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Local Network Assessment

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Preface

This report is submitted as partial completion of a series of studies being conducted for the U.S. Army Information Systems Management Activity at Ft. Monmouth, New Jersey, under Project Order Number 4-02-RD.

Certain commercial names are identified in this report to specify and describe some of the necessary information. Such identification does not imply exclusive recommendation by the National Telecommunications and Information Administration.

The views, opinions, and/or findings contained in this report are those of the author and should not be construed as an official Department of the Army position or decision unless designated by other official documentation.

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LIST OF ACRONYMS

ABM	- asynchronous balanced mode
AC	- access control
ACC	- Advanced Computer Communications
ACM	- access control machine
ADCCP	- advanced data communications control procedures
AH	- application protocol header
AM	- amplitude modulation
ANSC	- American National Standards Committee
ANSI	- American National Standards Institute
AP	- application
AUI	- attachment unit interface
b/s	- bits per second
BDU	- boundary data unit
BIU	- bus interface unit
BRAP	- Broadcast Recognition with Alternating Priorities
CATV	- Community Antenna Television
CBX	- computerized branch exchange
CCITT	- International Telegraph and Telephone Consultative Committee
CI	- computer interconnect
CRF	- central retransmission facility
CS	- communications server
CSMA/CA	- carrier sense multiple access with collision avoidance
CSMA/CD	- carrier sense multiple access with collision detection
DA	- destination address
DCE	- data circuit-terminating equipment
DDN	- Defense Data Network
DEC	- Digital Equipment Corporation
DIS	- draft international standard
DNA	- digital network architecture (DEC)
DoD	- Department of Defense
DSAP	- destination service access point
DTE	- data terminal equipment
ECMA	- European Computer Manufacturers Association
ED	- end delimiter
EFS	- end of frame sequence

EMI	- electromagnetic interference
FC	- frame control
FCS	- frame check sequence
FDDI	- Fiber Distributed Data Interface
FDM	- frequency division multiplex
FEP	- front-end processor
FOC	- fiber optic cable
FS	- frame status
FSK	- frequency-shift keying
GS	- gateway server
GTE	- General Telephone and Electronics
HDLC	- high-level data link control
HILI	- high level interface
HSLN	- high speed local network
IBM	- International Business Machines Corporation
ICI	- interface control information
ID	- interface data
IDU	- interface data unit
IEEE	- Institute of Electrical and Electronics Engineers
IFM	- interface machine
IMP	- interface message processor (from Bolt Beranek and Newman Publication # 1822)
IP	- internet protocol
IS	- international standard (ISO)
ISDN	- Integrated Services Digital Network
ISN	- Information Systems Network
ISO	- International Organization for Standardization
IWU	- interworking unit
kb/s	- kilobits per second
LAN	- local area network
LAPB	- link access procedure, B mode
LCN	- loosely coupled network
LDDI	- Local Distributed Data Interface
LED	- light-emitting diode
LLC	- logical link control

LIST OF ACRONYMS (CONT.)

MAC	- medium access control
MAN	- Metropolitan Area Network
MAU	- medium attachment unit
Mb/s	- megabits per second
MDI	- medium dependent interface
MIC	- medium interface connector
MIL-STD	- military standard
NAD	- network access device
NBS	- National Bureau of Standards
NMT	- network management
OSI	- Open Systems Interconnection
OSIE	- Open Systems Interconnection Environment
PABX	- private automatic branch exchange
PBX	- private branch exchange
PCI	- protocol control information
PDU	- protocol data unit
PH	- protocol control information header
PHY	- physical
PIN	- positive-intrinsic-negative photodiode light detector
PLL	- phase lock loop
PLP	- packet layer protocol
PLS	- physical signaling sublayer
PMA	- physical medium attachment
PMD	- physical medium dependent
PNX	- Private Network Exchange
PPP	- priority bits (token ring)
PSK	- phase-shift keying
PSPDN	- packet-switched public data network
RRM	- regenerative repeater machine
RRR	- reservation bits (token ring)
QPSK	- quadrature phase shift keying
SA	- source address
SAE	- Society of Automotive Engineers
SAP	- service access point
SD	- start delimiter

LIST OF ACRONYMS (CONT.)

SDU - service data unit
SFD - start frame delimiter
SMT - station management
SNA - systems network architecture (IBM)
SPC - stored program control
SSAP - source service access point
TAG - technical advisory group
TCP - transport control protocol
TCU - trunk coupling unit
TDM - time division multiplex
TDMA - time division multiple access
TPW - twisted-pair wire
UD - user data
VCS - virtual circuit switch
WAN - wide area network
XNS - XEROX network systems (protocol)

LOCAL NETWORK ASSESSMENT

D. V. Glen*

Local networks, related standards activities of the Institute of Electrical and Electronics Engineers (IEEE) Project 802, the American National Standards Institute (ANSI), and other elements are presented. These elements include 1) technology choices such as topology, transmission media, and access protocols; 2) descriptions of standards for the 802 local area networks (LAN's); high speed local networks (HSLN's) and military specification local networks; and 3) intra- and internetworking using bridges and gateways with protocols conforming to the framework of the Open Systems Interconnection (OSI) reference model. The convergence of LAN/PBX technology is also described.

Key words: baseband, broadband, carrier sense multiple access with collision detection (CSMA/CD); high-speed local network (HSLN); IEEE project 802; internetworking; intranetworking; local networks; local area networks (LAN); Open Systems Interconnection (OSI); private branch exchange (PBX); token bus; token ring

1. INTRODUCTION

1.1 Background

Local networks exist in numerous combinations of topologies, transmission media, levels of connectivity, signaling, and access methods. They also exist in various degrees of conformance with standards that have been or are being developed and changed. There are multiple standards because no single network serves the needs of all users.

The existence of local networks is based on the desire to exchange data between and within systems, to share resources such as printers and storage devices, and to provide redundancy if a failure should occur in part of a distributed system. One definition is, "A local network is a communications network that provides for the interconnection of a variety of data communications devices within a small area" (Stallings, 1983). A number of local network attributes are ascribed to this definition. A local network is:

- a communications network, not a computer network
- for data communicating devices such as computers, terminals, peripherals, machines or processes

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- intended to encompass a small geographic area such as a building, a group of buildings, a college campus or military base
- typically, privately owned

Local network technology development may be considered to be of two origins. One source is that related to Local Area Network (LAN) technology; the second is related to telephony. The LAN technology evolved from experiments in topology and media behavior when user terminals were connected to computers in the late 1960's. At the same time, the ARPANET program, with sponsorship of the Department of Defense (DoD), produced formats and protocols that would prove useful in LAN's. Another predecessor of LAN development is the work on packet radio through the ALOHA project at the University of Hawaii (Tannenbaum, 1981). Combined with a significant amount of additional effort, these have led to the LAN's.

The second type of local network technology development is related to telephony. In the predominant, current form, analog voice and nonvoice (e.g., facsimile, television) communication is separate from data communication. Digital technology permits combining the traditionally analog information with that related to data processing. This results in an integrated voice/data local network through the use of the digital private branch exchange (PBX), or a computerized branch exchange (CBX).

More recently, another area of local network development is taking place. Local networks have evolved from a need for data communications. Usually, voice communications have been bypassed, although integrated voice/data processing controllers are appearing on the market. These are devices that function as PBX's, but are LAN's with digital voice/data switch controllers.

Local networks may be considered to be in five categories: LAN's, LAN/PBX, High-Speed Local Networks (HSLN's), PBX/CBX, and data switches.

The five local networks in Figure 1-1 are designed for certain applications that are related to appropriate data rates (Table 1-1).

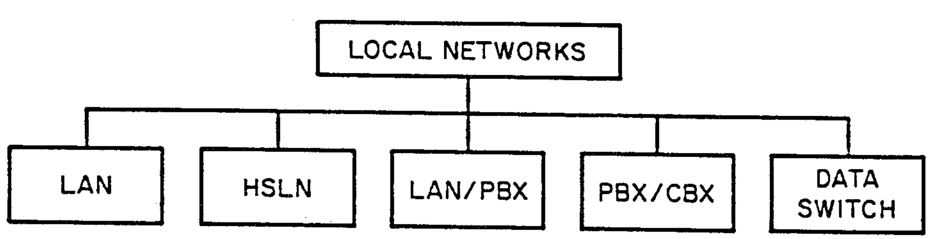


Figure 1-1. Types of local networks.

Table 1-1. Range of Local Network Main Channel and End-User Data Rates

Local Network	Applications	Transmission Speed (b/s)	End-User Rate (b/s)
LAN	DATA	10M	19.2 to 10M
HSLN	COMPUTER DATA	50M	50M
LAN/PBX	VOICE, DATA	50M	1.5M, 50M
PBX/CBX	VOICE, DATA	1.544M	19.2K, 64K
DATA SWITCH	DATA	650K, 1.544M, 5M	230K

The accepted definition of a LAN, i.e., of limited distance capability, owned by a single organization, while permitting various terminal devices to communicate, can apply to all of these local network categories. Each of these local networks tends to lean toward services that are voice or data oriented. The LAN's are data oriented, while the PBX's are voice communications oriented, despite data function add-ons. A PBX/CBX network, although having data capabilities, is used primarily for voice traffic that constitutes in excess of 80% of office traffic. The HSLN and data switch networks function purely for data transfer. Although a rivalry appears to exist between LAN and PBX functions, neither appears to provide an ideal solution for combining voice and data services. Perhaps the local networks coming closest to a universal solution will exist within the LAN/PBX network. The LAN/PBX attempts to combine the best features of LAN's for data transfer and PBX's for voice switching. An awareness of the strengths and weaknesses of these systems as well as the extent of capital investment for installed PBX's is needed during the selection process of a local network.

1.2 Purpose and Scope

The intent of this report is to provide a tutorial overview of local networks, LAN standards, and connectivity between LAN's or other networks.

This report is oriented toward the first three categories in Table 1-1. These are the LAN, the HSLN, and the LAN/PBX types of local networks. An emphasis is placed with these in terms of standards that have been developed by the Institute of Electrical and Electronics Engineers (IEEE) project 802 for local area networks, and the American National Standards Committee (ANSC)

X3T9.5 for high-speed local networks. Descriptions are given of the LAN/PBX devices and to some extent, the relation between PBX's and LAN's. Data switches are not covered in this report.

Extensive coverage is given in this report to the topologies, transmission media, and local network medium access methods, including contention and deterministic approaches. Intra- and internetworking of LAN's through the use of bridges and gateways are described in terms of the Open System Interconnection (OSI) reference models of the International Organization for Standardization (ISO) IS 7498 and the International Telegraph and Telephone Consultative Committee (CCITT) Recommendation X.200. The protocols within the structure of the OSI model are part of the description.

1.3 Organization of This Report

The report is organized on a progressive basis. It starts with a description of the components that comprise the local networks and concludes with the complete systems.

Section 2 provides a description of the technology upon which local networks are based. This includes the various topologies such as bus, ring and star, and the transmission media such as twisted-pair wire, coaxial cable, and optical fiber. A facility cabling plan is also included. Various access protocols are described. This encompasses contention methods for Carrier Sense Multiple Access (CSMA), including Collision Detection (CD), and deterministic methods such as token ring and token bus. Performance comparisons are made of the various topologies and access protocols.

Section 3 provides an extensive description of the LAN standards of IEEE Project 802. This section also presents discussions of the Local Data Distributed Interface (LDDI) and Fiber Distributed Data Interface (FDDI) standards of ANSC X3T9.5. Local network standards for the DoD, MIL-STD-1553B and 1773, are also part of Section 3.

Section 4 covers both intra- and internetworking. A two-tier approach is used to relate abstract network functions using layering of the OSI reference model with "real" systems such as LAN's, long-haul networks, bridges, and gateways.

Section 5 includes descriptions of a method for protocol conversion and three LAN/PBX configurations, the short bus topology, and two networks that connect distributed switching/controller nodes with ring network LAN's.

Section 6 is a summary of the report and includes a list of factors to consider when selecting a local network.

Appendix A is a description of the OSI reference model.

Appendix B provides a list of protocols that are applicable to the layers of the OSI reference model. This provides an index to the protocols that are applicable to the local networks.

2. TECHNOLOGY CHOICES

This section will describe and discuss the technical choices related to local networks. The choices consist of topology, transmission media, media access methods, and higher level service protocols (Figure 2-1).

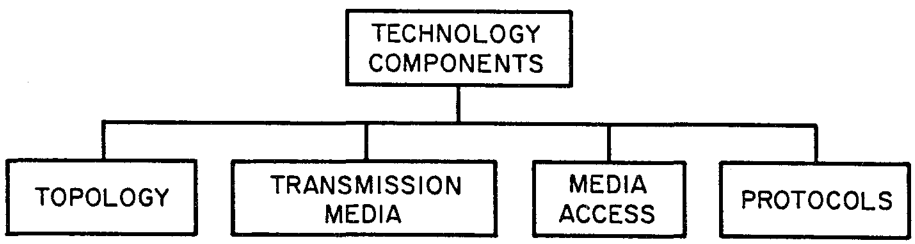


Figure 2-1. Local network technology choices.

Each of these choices has a limited number of associated basic alternatives. There are three topologies, three transmission media, three media access methods, and an indeterminate number of higher level protocols required for various services dependent on user applications. While the above technology choices specifically apply to LAN's, they also relate to the five types of local networks mentioned in Section 1. The following sub-sections will describe the first three choices of Figure 2-1. The protocols are included as part of the discussion Sections 3, 4, and 5.

2.1 Topology

A communications network can be classified according to a number of criteria, whether relating to economics, flow control, or switching techniques (i.e., circuit, message, or packet switched). Each of these classifications is related directly, or indirectly, to network topology. A local network is designed and/or built with a certain pattern, or topology, in mind. It is a logical and physical arrangement of points such as user stations and locations. Selection of a specific topology is important because it impacts cost, reliability, ease of connectivity, circuit delay, and complexity of a network.

There are three basic forms that are related to cable (i.e., local network) topologies (Figure 2-2). These are the bus, ring, and star, although each has variant forms. The characteristics of these basic topologies are as follows:

- Bus - one or more cables interconnect devices for information transfer with a central or distributed control mechanism.
- Ring - information is transferred in a "circular" direction between points without a central switch.
- Star - a central switch makes point-to-point connections for information transfer.

Bus. One or more cables interconnect devices (or stations) for information transfer with a central or distributed control mechanism. Each station has 1) a connection to the transmission medium and 2) a unique identifying address. Messages are broadcast bidirectionally along the bus to all stations. Each station "listens" for its address and accepts data upon address recognition.

With centralized control, messages are first sent to a controller and then retransmitted to the destination. Centralized control through polling asks each station for information to be transmitted. A second form of centralized control exists when each station requests the controller for transmission slots or permission for a message to be sent to its destination.

With distributed control (i.e., decentralized control), the control logic is imbedded in each of the stations connected to the bus.

Ring. Information is transferred in a circular, usually unidirectional path between stations under centralized or distributed control. The signal is regenerated as it passes through each station while traversing the ring. The ring is essentially a point-to-point configuration because of the regeneration characteristic. Fiber optic cable can be easily used because of the point-to-point feature.

Failure of a single station can disable an entire network but measures can be taken to enhance reliability. These can be through a dual ring, through a by-pass mechanism, or through a star-wired ring.

In the dual ring, two complete signal paths pass through each station. Signal transmission in one ring is counter to the other. If a station fails,

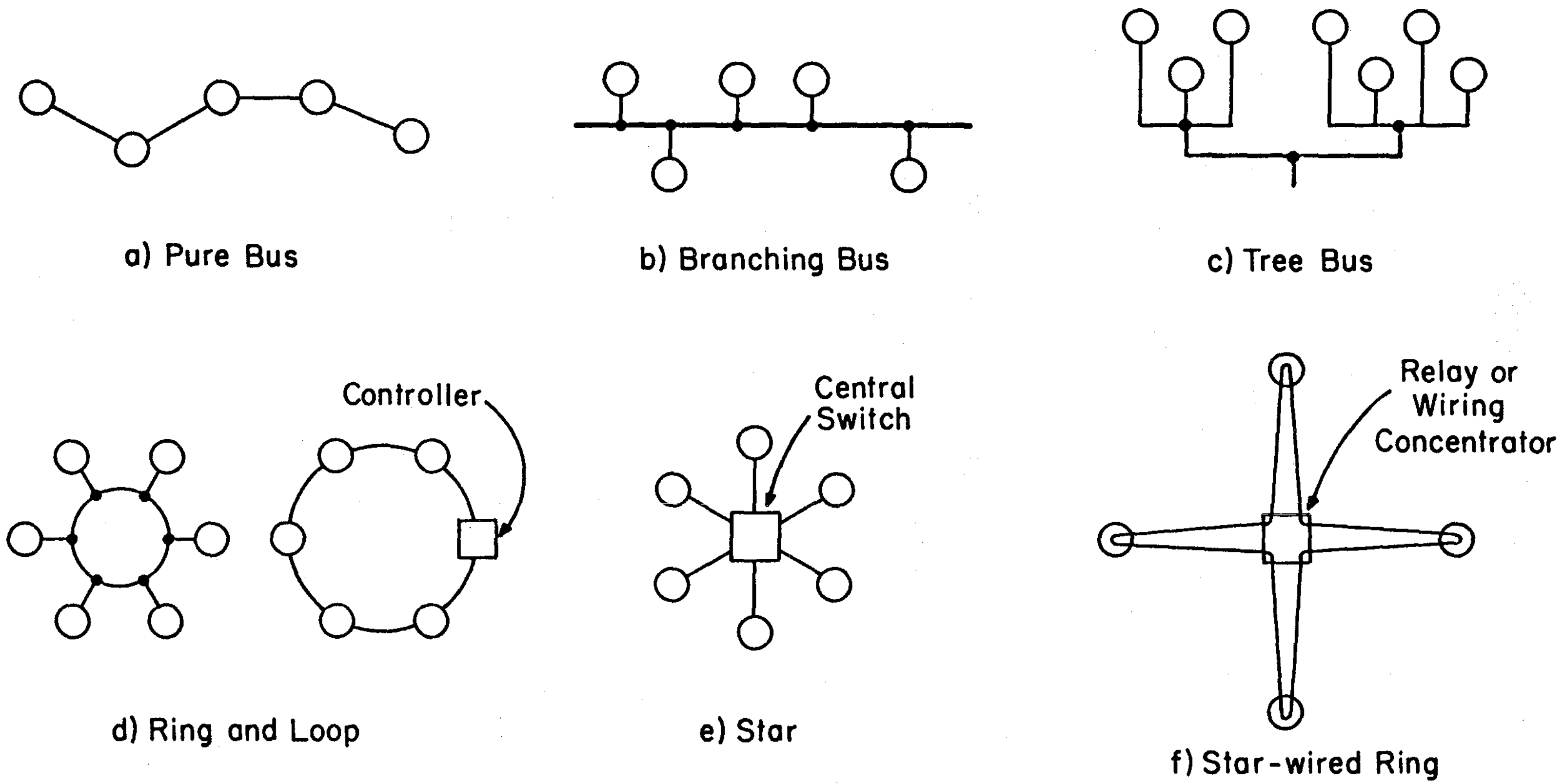


Figure 2-2. Basic topologies and variations.

Table 2-1. Comparison of Basic Topologies

	Bus	Ring	Star
Advantages	• Low cost	• Lowest cost per station	• Analogous to phone system
	• Uses least cable	• Signal regeneration extends operating distance	• Failure isolation through central control
	• Failure of a station will not disable bus	• Constant performance characteristic	• Operation independent of user devices
		• Can use fiber optic cable (point-to-point station connection)	• Integration of voice and data services
Disadvantages	• Difficult to detect cable breaks	• Network disabled with station failure or cable break	• Requires most cable
	• Not suitable for fiber optic cable (difficult to tap)		• High initial cost
	• Loading decreases performance		• Network disabled if central switch fails
			• Relatively limited bandwidth

automatic reconnection to complete the path is made via the second ring. Cost of the network increases because of the added redundancy.

The star-wired ring physically appears to be a star topology, but logically it operates as a ring. The central point of the configuration can be a relay center or wiring concentrator. Should a station fail, the center-concentrator can drop the failed station and reconfigure the ring. In practice, a secondary ring is also used in the network.

Star. A central switch makes station-to-station connections through which all user information must pass. All stations in the network are connected to the central switch on a point-to-point basis via dedicated lines. Since the central switch controls all communication, requests are made to the switch by the transmitting station to establish a path to the receiving station. The entire network is crippled if the central switch fails. An example of a star topology is the PBX in an office telephone system where reliable operation has been demonstrated.

2.2 Transmission Media

Among the design choices to be made for a local network is the selection of a transmission media. These media can be bounded or unbounded (Figure 2-3). The bounded media are the most popular and consist of twisted-pair wire, coaxial cable, and fiber optic cable. The unbounded media consist of radio, microwave, and infrared transmission. The unbounded media are useful where cable right-of-way is a problem and across bodies of water. However, relatively few systems are commercially available and regulatory problems may enter into making frequency assignments.

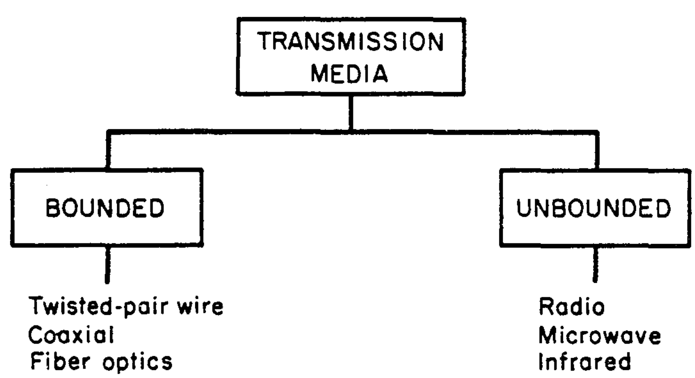


Figure 2-3. Transmission media.

The terms, "baseband" and "broadband" are generally used within the context of coaxial cable transmission media. However, an explanation is necessary.

Baseband technology provides multiple communication channels over a single bus using time division multiplex (TDM) transmission techniques. Broadband technology is capable of providing multiple communication channels over a single communications bus using frequency division multiplex (FDM) transmission techniques.

While baseband and broadband technology is frequently related to coaxial cable transmission media as baseband coax and broadband coax, the coupling of these terms appears restrictive. Baseband technology is not limited to coaxial cable media, it can also use twisted-pair wire, Community Antenna Television (CATV) cable, and fiber optic media. Broadband technology, in contrast, depends on rf signal transmission through coaxial cable media, primarily CATV cable.

2.2.1 Twisted-pair Wire

Twisted-pair wire is a short-haul medium in contrast to radio, coaxial cable, and satellite that are used for long-haul signal transmission. Twisted-pair wire is used for telephone subscriber loop connections and has been 19-gauge wire. Smaller gauge wire such as 26- or 28- gauge is currently being installed in buildings.

The twisted-pair wire is the least expensive medium and readily available, but it is more susceptible than the other media to electrical and electromagnetic interference. It has a lower loss characteristic than untwisted wire due to the cancellation of fields that are generated by current flowing in the wire. Further improvements in characteristics are made by creating different pitches in multipair wiring within a sheath. The different pitch in the wire spiral helps eliminate interference and crosstalk. Multipair wire can be two-pair in a house, 25-pair in a building, or 3,600-pair for interoffice trunks.

Shielded twisted-pair wire (also called screened cable) has a conducting shield added between or around wire pairs before an external sheath is created. This reduces radiation from the screened cable, as well as pickup from external sources. Both the multipair and screened cable can transmit T1 carrier at 1.544 Mb/s (Table 2-2).

Table 2-2. Transmission Media Characteristics

Characteristics	Twisted-pair Wire	Coaxial Cable		Fiber Optic Cable
		Baseband	Broadband	
Cost				
-Initial	Low	Moderate	High	Highest
-Maintenance	Low	Low	Low	Low
EMI Susceptibility	Very high	Greater than broadband	Less than baseband	None
Availability	In-place or readily available	Off-the-shelf	Off-the-shelf CATV	Developing, available
Bandwidth	1.5 Mb/s @ 1.5 km 56 kb/s @ 5 km	10 Mb/s	10 Mb/s 350 Mb/s aggregate	1 Gb/s-1 km 100 Mb/s-10 km
Maximum no. of stations	>1000	>1000	~25,000	>1000
Distance	~2 km	3 km to 10 km	10 km to 50 km (with repeaters)	>10 km
Propagation	unidirectional	bidirectional	unidirectional	unidirectional
Topology (preferred)	bus, ring, star, tree	bus, ring, star	bus, tree	star, ring
Signal type	Single channel, analog or digital	Single channel, digital	Multichannel, analog	Single channel, digital lightbeam

Signal processing characteristics at an interface such as RS-232-C, where one side is grounded, are the most significant drawback to a higher data transmission rate through twisted-pair wire. The RS-232-C unbalanced circuit standard specifies 20 kb/s for 15 meters. In contrast, the RS-422-A balanced interface circuit standard specifies 10 Mb/s for 12 meters with extension to tens of meters with "good engineering practices." The RS-422-A standard also specifies 100 kb/s for 1200 meters with extension to several kilometers, again using good engineering practices. Recent experiments have successfully used the RS-422-A balanced interface with twisted-pair wire at rates of 4 Mb/s at a distance greater than one kilometer.

2.2.2 Coaxial Cable

Coaxial cable is the most popular medium used for LAN's. Coaxial cables are of concentric form with a single, center conductor, surrounded by an insulating dielectric, followed by a shielding conductor and an insulating jacket. At high frequencies, current is carried by the "skin" of the center conductor. This is called a "skin effect." The radiating electromagnetic field is confined between the center conductor and the shield. This limits the energy loss through radiation and also offers less susceptibility to electrical noise or electomagnetic interference. (Coaxial cables that house two- or three-shielded conductors are called twin-axial and tri-axial cables.)

Coaxial cable is more expensive than twisted-pair wire but it can carry higher frequencies over longer distances (Table 2-2). It is suitable for point-to-point and multipoint user applications that are permitted through low-loss, easily-installed bridge taps. There are two categories of coaxial cable based on the type of modulation technique being used on the coaxial media: baseband and broadband.

Baseband coaxial cable uses digital signaling where user data is represented by a series of "on" and "off" voltage transitions. Transmission of data at 10 Mb/s is common, although 50 Mb/s is possible with special equipment. Point-to-point and multipoint communication is possible. Resource sharing among many users is possible through time-division multiplexing (TDM).

The baseband technology is usually a bus topology because digital signals cannot be easily propagated through splitters required for a tree architecture. Signal transmission from a station is bidirectional along the cable. The baseband coax has impedances of 50 ohms (i.e., RG-8/U), 93 ohms (i.e., RG-62/U), and 50 or 74 ohm Ethernet cable. Simple taps are used to pierce the sheathing and make easy connections. The operating distance is limited to approximately 2 km, but reliable repeaters and amplifiers can be used to extend operating distance to 15 km (Table 2-2).

Modulation of the digital signals by the Data Terminating Equipment (DTE) is not required as it is for a broadband system. The digital signals are impressed directly on the media. This simpler technology makes it less expensive than broadband. However, fewer nodes can be connected.

Digital baseband is more susceptible than analog broadband to low frequency electromagnetic interference (EMI) and electrical noise. The noise immunity is on the order of 50-60 dB.

Transceivers interchange data using a variety of coding techniques. One type, NRZ, requires separate clocking. Manchester phase encoding is the most common because of its self-clocking characteristics. No separate clocking is needed, which is necessary with a single channel two-conductor system. A "one" is indicated by a positive transition and a "zero" is indicated by a negative transition in a bit "cell" or unit of time.

Broadband coaxial cable carries analog signaling where digital or analog signals sources are converted through an rf modem for transmission. Community antenna television (CATV) technology provides the hardware for signal transmission. The rf spectrum may go from 50 MHz to 300 MHz, or 50 MHz to 400 MHz in 6 MHz CATV channel increments using frequency division modulation (FDM). Other bandwidth allocations are possible depending on the LAN provider.

The broadband technology can be a bus/tree topology because the analog signals can be branched through low-cost signal splitters and taps. The broadband coax has a 75-ohm (i.e., RG-59 CATV cable) impedance. The operating distance can be extended to 50 km using amplifiers particularly because it is less susceptible to EMI compared to baseband.

All points attached to a broadband coaxial cable can receive the transmitted signal. Broadband signals are unidirectional in traversing the media cable, although two transmission techniques are used; a single cable system and a dual cable system.

In a single cable system, stations transmit on a low frequency through a "reverse" channel, and receive on a higher frequency using a "forward" channel after frequency translation through a head-end or central retransmission facility (CRF). Cable channel assignments are in "bandsplits" called midsplit which is most common, or subsplit. Midsplit and subsplit cable systems are shown in Figure 2-4. Data traffic is usually midsplit while video traffic is subsplit.

The available bandwidth is divided between transmitting and receiving to constitute a full-duplex system.

In a dual-cable system, stations transmit and receive on the same frequency (Figure 2-5). In practice, a single cable loops past each station twice. A head-end is not needed in a dual-cable system as is required by a single-cable system. Costs are higher for a dual-cable system than a single-cable system due to twice the number of taps and amount of cable that is needed. However, the available bandwidth is twice as great.

Broadband systems are less susceptible than baseband systems to EMI. The noise immunity is on the order of 85-100 dB for broadband compared to 50-60 dB for baseband.

Frequency-shift keying (FSK), phase-shift keying (PSK) and amplitude modulation (AM) are modulation techniques available from vendors. Quadrature phase shift keying (QPSK) has been proposed by the Institute of Electrical and Electronic Engineers (IEEE).

The presence of multiple FDM channels in a broadband system permits a number of modulation schemes, digital or analog signal sources, and a greater number of user nodes (~25,000). Broadband applications include low-speed data channels (~300 b/s), switched voice channels, high speed data channels (1 MB/s to 10 Mb/s), and analog video channels.

The cost of broadband cable is approximately 1.5 times greater per foot than baseband cable. The cost of a broadband system is also increased by the need for modems which may be of two types. One is the fixed-frequency type that transmits and receives on only one frequency. The second type is frequency-agile where the send and receive frequency-pairs can be selected by software control.

2.2.3 Optical Fiber

Data transmission on optical fiber cable is analogous to baseband coaxial cable where there is one band per cable. Optical fiber cables are generally smaller and lighter than twisted-pair and coaxial cables.

A single strand of optical fiber is a thread-like structure which, in its simplest form, has a lightguiding region called a core. The core is surrounded by a coaxial outer layer of material called the cladding. The optical properties of these two regions are selected so that light is totally reflected within the core-cladding interface. This allows many "modes" to propagate through the core of the fiber. Such multimode fibers are currently being used

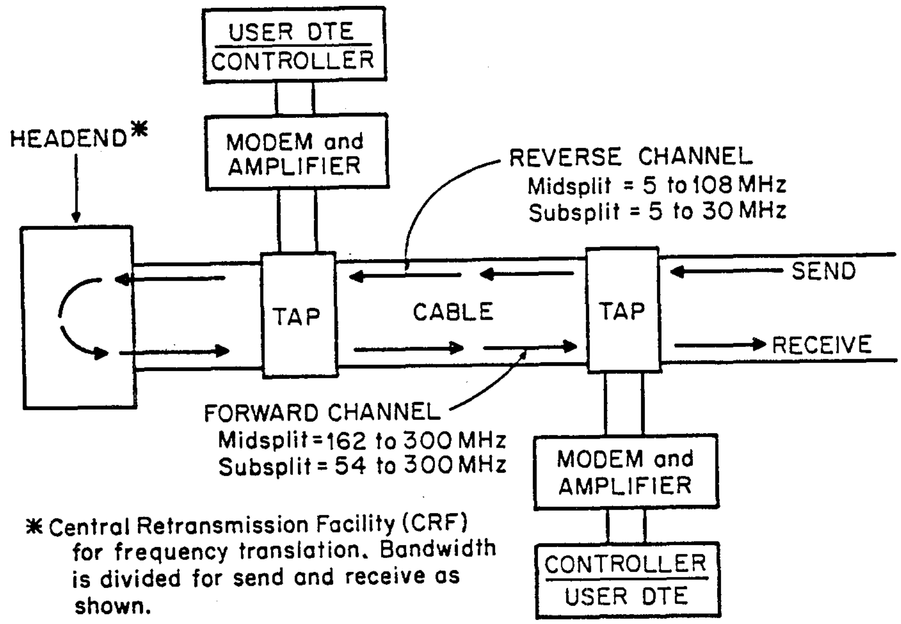


Figure 2-4. Single-cable broadband (after Omnicom, 1984a).

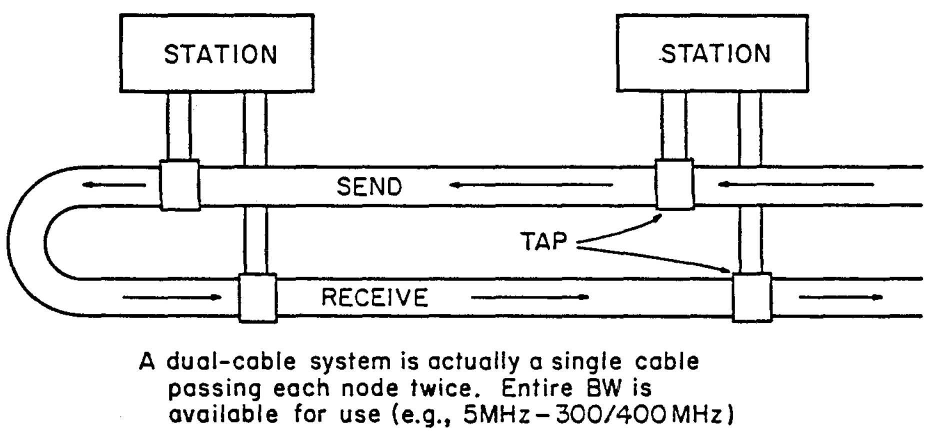


Figure 2-5. Dual-cable broadband (after Omnicom, 1984a).

as LAN transmission media. Specific standards for core size and outside diameter are being debated for this application.

The light sources are usually light-emitting diodes (LEDs) in the visible or infrared range (i.e., 10^{14} to 10^{15} Hz). Lasers are also used as light sources. At the receiving end, a photodiode light detector [i.e., positive-intrinsic-negative, (PIN)] detects the incoming signal. At the transmitter, modulating data signals are translated from the electrical domain to the optical domain. At the receiver, the signals are converted from the optical domain to the electrical domain.

There are a number of advantages and disadvantages in using optical fiber cable for local networks. The advantages include the following:

1) An extremely wide signal bandwidth. Transmission rates of 420 Mb/s over 200 km and 2 Gb/s over 130 km path lengths have been achieved without repeaters in laboratory demonstrations.

2) There is no EMI radiation or pickup. The lack of radiation is beneficial to message security. Stray radiation can be detected from non-optical systems to divulge information. Additional security from intrusion exists because the fiber has to be cut to make a tap. Cable damage or intrusion can be detected to close tolerances (i.e., 2.5 cm within one km) so that security is maintained.

3) Electrical isolation eliminates grounding and ground loop problems.

The disadvantages include the following:

1) The cost of fiber-optic cable exceeds coax by a factor of four or five. Based on bandwidth-distance factors the cost factor is advantageous.

2) Fiber is not well-suited to multidrops and is better-suited for point-to-point linking. Tap losses are too high, although this technology is improving. Star topology, where connections are made through a central switch, is frequently preferred for fiber cable. Fiber is also applicable in ring topologies. Expensive optical couplers, taps, and multiplexing techniques limit extensive use for multidrop applications.

3) Cable connection is considered relatively difficult and costly. Each fiber of a multifiber cable has to be precisely aligned for a connection.

Future application and use of optical fiber cable in local networks holds exceptional promises as engineering and manufacturing techniques improve and lower costs are expected.

2.2.4 Facility Cabling System Media

A cabling plan for buildings under construction and buildings to be renovated has been announced by the IBM Corporation (IBM 1984a, 1984b, 1984c). The cabling plan specifies the wiring in a building to provide an outlet in every office that will support end-user devices such as terminals and telephones. The plan to provide data connection outlets is analogous to the ubiquitous telephone jacks and plug connections.

The basic medium is shielded twisted-pair wire. A single, mixed media cable contains shielded twisted-pair wire for data and unshielded twisted-pairs for voice communications (Figure 2-6). The cables may contain two twisted pairs of No. 22 AWG solid wire with braided shield and sheath covering. Another type has two twisted-pairs of No. 22 AWG solid wire with braided shield and four additional pairs of wire between the shield and sheath. According to IBM, the shielded twisted-pair wire can carry 10 Mb/s and was chosen on the basis of lower cost, ease of installation, and mature technology. Line amplifiers are needed for extended runs.

User devices are connected to outlet plates in the office. Wiring connects the office outlet plate to distribution panels in wiring closets. Patch cables at the distribution panel can be used to connect offices as required.

Twin-axial and dual fiber optic cable are available as needed for use in the cabling plan. The cabling plan is not a local network. A local network that will use the cabling plan has been announced by IBM as being available in 1986 or 1987. That local area network will use a token-ring architecture and other components that are planned.

2.3 Access Protocols

Access protocols are used to determine which station will have the right to send messages on a network. Controlling that right is a function of two basic design elements. The first element is based on control strategy which may be centralized or distributed. The second element is based on the access method, which may be controlled or on demand.

Centralized control of a network resides with a <u>single</u> processing center, or device, through which all messages that travel between stations will pass. In contrast, distributed control is based on the network containing several processing devices that may be capable of determining message flow.

The demand access method is based on a station claiming the right of entry to the network when, for example, messages are ready to send. On the other

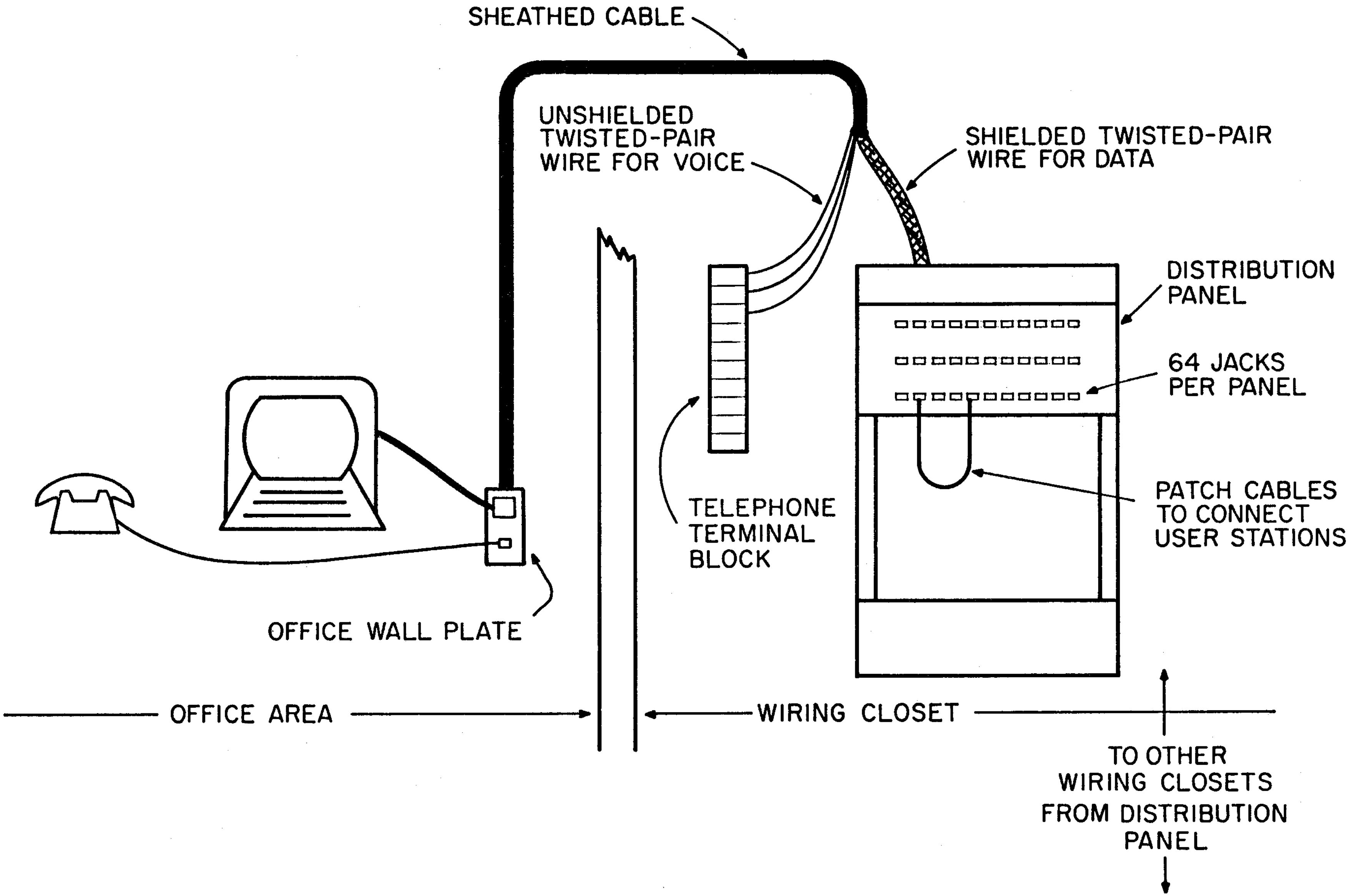


Figure 2-6. Facility cabling plan (after IBM, 1984c).

hand, the controlled access method depends on a predetermined methodology for gaining access to a network. The combining of control and access methods leads to four types of access protocols that can have a number of variants (Table 2-3).

Table 2-3. Access Protocols

CONTROL METHOD	ACCESS METHOD		TOPOLOGY
	DEMAND	CONTROLLED	
CENTRALIZED	CIRCUIT SWITCHING	POLLING	STAR
DISTRIBUTED	CONTENTION (Table 2-4)	NON-CONTENTION OR DETERMINISTIC (Table 2-5)	BUS OR RING

The circuit switching and polling access protocols are usually associated with a star topology; contention and deterministic access protocols are associated with bus and ring topologies.

2.3.1 Circuit Switching

Circuit switching is usually related to telephony where a central controller establishes a connection between two stations for the duration of a telephone call or the period necessary to transfer a data message. The PABX is an example of circuit switching with centralized control and demand access in a star topology network. While related to analog technology in the past, the current PABX's employ high-speed digital switching techniques for voice and data. The basic intent is to connect pairs of wires between telephones or data devices.

2.3.2 Polling

The polling access protocol uses the centralized control in combination with a controlled access method. Polling requires a master controller in charge of the network, usually in a star topology, although it is applicable to any topology. Each station on the network is sequentially polled to determine whether or not access to send messages is desired. Polling algorithms in the controller determine the order in which stations are queried as to whether information is available for transmission back to the controller (e.g., a host computer). Depending on the expected data transmission requirements of a station, the algorithm can be used to query some stations more frequently than others. On a multidrop bus, for example, all stations will see the query, but will respond only when they recognize their own unique address (Figure 2-7).

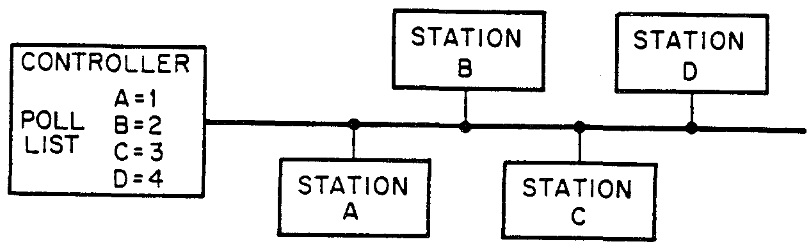


Figure 2-7. Polling access for a multidrop bus.

2.3.3 Contention

Contention is the next access protocol to be considered. Contention protocols are indicated in Table 2-3. This is a distributed control combined with demand access. Table 2-3 indicates a reference to Table 2-4 for contention access.

Table 2-4 shows a comparison of six contention access protocols. The table is intended to provide a simplified examination of the operation (e.g., algorithms) for these contention techniques.

Two basic types of contention schemes are shown. The first two are the pure and slotted ALOHA that were initiated at the University of Hawaii for packet radio transmission (Tannenbaum, 1981). The second group of contention access protocols is called Carrier Sense Multiple Access (CSMA). That section of the table starts with the 1-persistent CSMA and ends with collision detection (CD).

The pure ALOHA access protocol uses the approach of message packet transmission whenever data is ready. A lack of acknowledgment indicates that the message has not been received or a collision occurred. A new transmission occurs after waiting a random amount of time.

In the slotted ALOHA protocol, a discrete slot time is employed for initial and repeat transmission time. The advantage of slotted ALOHA is that

State	S (CSMA)	
	Pure Al	Collision Detection (CD)
STATION CONDITION: data ready to send.	• does not ses channel.	• station senses channel.
CHANNEL CONDITION: Busy.	• send anytn time to await ackability. ment.	• station senses channel until it is idle.
CHANNEL CONDITION: Idle.	• send anytnsmits with await ack p; waits ment. ot with of trans- -p, stop	• station transmits immediately upon detecting idle, continues to sense.
CHANNEL CONDITION: Collision.	• cease tranission after senng complete packet; wt random amount ofime to re- send. algorithm.	• cease transmission during packet sending; send jamming signal to indicate collision, wait random amount of time to repeat algorithm.
COMMENT	• partial o to slot loss of pques. on collis	• modified 1-persistent • most efficient through-put. Use for LAN.
THROUGHPUT EFFICIENCY	18%	90%

only one packet can be lost due to collision. In pure ALOHA, there can be partial damage to two packets, resulting in the loss of both.

The CSMA is similar to pure ALOHA except that it determines if another station is currently transmitting a packet. The carrier sense (listen before send), multiple access (for multiple users, send when channel is free) technique can employ a number of CSMA techniques. The 1-persistent, nonpersistent, p-persistent, and collision detection (CD) access protocols are compared in Table 2-4.

The CSMA/CD is the contention access protocol most frequently associated with LAN's. As with the other CSMA techniques it senses the transmission channel before sending. The difference is that it continues to sense the channel to detect a collision while sending. The others do not. If a collision occurs, the transmission of a packet stops immediately. Then, as in the other protocols, retransmission occurs after a random amount of time.

Collisions are detected in a baseband network when the voltage magnitudes are higher than those that exist when transmission is that of a single user. Collisions are detected in a broadband network by comparing the transmitted and received signals on a bit-by-bit basis, either at the head-end or the sending station.

Another approach allows the use of a noncontention, collision-free protocol to be used with CSMA. This is a reservation approach that results in collision avoidance (CA) on a local network, and in one access protocol form is known as CSMA/CA.

There are a number of collision-free protocols. Among them are the basic bit-map and the Broadcast Recognition with Alternating Priorities (BRAP) protocols (Tannenbaum, 1981).

For a bit-map protocol, assume that there are six stations on a network and that stations 1, 3, and 4 have information to send. As a series of contention slots are circulated in a network, each station with ready data packets inserts a 1 into its assigned slot (Figure 2-8). Each of the slots is reserved for a specific station that will indicate whether it wants to send; each station can insert a 1 only at its assigned moment. After all the slots (e.g., N = 6) have circulated, each station is aware that stations 1, 3, and 4 wish to transmit. Transmission then begins, in numerical order, without collision, due to prior agreement. After station 4 completes its transmission, another series of N contention slots circulates and each station with a queued packet inserts a 1 in its assigned slot. There are two difficulties here. One, the "send" prospects for higher-numbered stations are better than for lower-numbered stations. On the average, a low-numbered station will have to wait N/2 slots, plus another full set of N slots before it can send. For all stations, the mean is N slots. Two, under light load a station must wait for the current slot scan to be completed before having an opportunity to transmit.

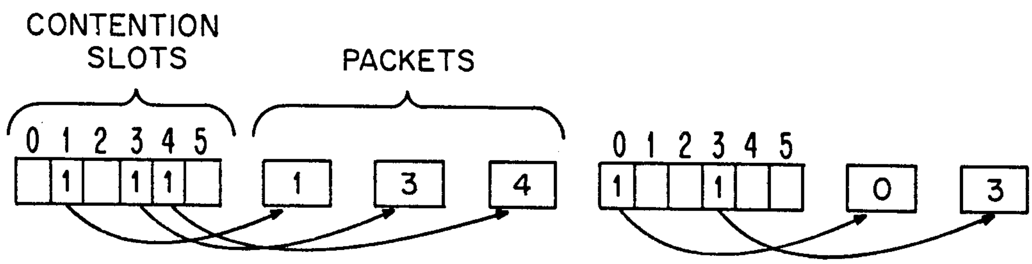


Figure 2-8. A basic bit-map protocol.

A second protocol overcomes these difficulties. It is called Broadcast Recognition with Alternating Priorities (BRAP) (Figure 2-9). Immediately after claiming its contention slot by inserting a 1, a station begins sending its packet. In BRAP, a bit scan starts with the station that just transmitted data. This is called transmission arbitration via a round-robin time-slot algorithm. Bit slots go by a station not wanting to send. Access is immediate when its bit slot passes and a station is ready to send.

Efficiency of BRAP is the same as a bit-map protocol, but delay characteristics are improved since the wait is an average of N/2 rather than N slots. A form of this protocol is used in proposed standards for the high speed, Local Data Distribution Interface, LDDI (Section 3.2).

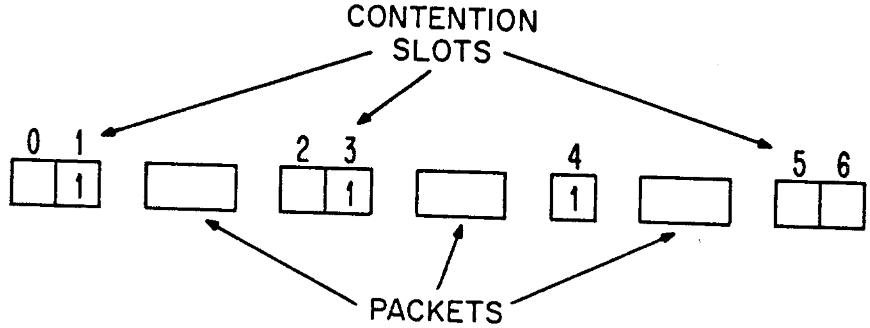


Figure 2-9. Broadcast Recognition With Alternating Priorities

The fourth and last category of access protocols in Table 2-3 is noncontention, or deterministic. It is distributed control combined with controlled access. Table 2-3 indicates a reference to Table 2-5 for this category.

Table 2-5 is a comparison of four noncontention access protocols that use token passing, or a form of it. It is similar to polling access, but without the central controller. Token passing was originally developed for ring topology, but has been extended to bus topology. The token consists of a packet of bits that is used to control transmission from each node on the network. The token is transferred from one node to the next. Upon receiving the token, the node has the right to access the medium. When message transmission is completed by the station, the token is passed to the next location implicitly, or explicitly.

Implicit token passing takes place on a physical ring (i.e., token ring). Each station always passes the token to the next station on line. Logic is not changed in this procedure whether a new station is added or another deleted. The token is allowed to pass to the next node if there is no message to send.

Explicit token passing takes place on a logical ring that exists as a physical bus (i.e., token bus). In this procedure, each node passes the token to a specific address location (Figure 2-10). A new node or malfunction requires that network logic be changed, since each node maintains a record of preceding and succeeding addresses. A connection interface unit reads the addresses on the bus and provides the logic to connect its station when its address is detected.

The token ring (Figure 2-11) has a repeater on the medium to regenerate the token and message bit streams sent on the ring. Every node sees all traffic and is to copy only the messages that are addressed to that node. The access time is deterministic in that the delay before a node receives the token is predictable.

The slotted ring (Figure 2-12), while similar to token passing, instead provides fixed-size slots (i.e., number of bits in a packet) that circulate around a ring. Bits in each packet indicate whether the packet is empty or full. As the slots circulate around the ring, each station with a message to send waits for an empty slot, marks it full, and fills the slot with data. As shown in Table 2-5, the message circulates to the receiving node, where the message is removed and the slot is marked empty.

Table 2-5. Comparison of NonContention Access Protocols

Mode	Access Protocol			
	Token bus	Token ring	Slotted Ring	Register Insertion
Listen	• token circulates around logical ring; maintain last and next station addresses.	• a free token circulates around ring, repeater copies to output.	• circulating slots marked empty/full.	• read circulating packets at insertion ring.
Message Ready	• seize token.	• seize token, repeater changes bit pattern for station connector.	• seize empty slot, mark full.	• hold incoming packet, if necessary.
Message Insertion	• send packets to destination address; transmit token to next address in logical ring.	• send packet(s), release free token; packets circulate through repeaters to destination.	• insert packet in slot; circulate to destination	• send packet in data gap.
Message Removal	• message copied by addressee.	• message circulated to originating station for receipt acknowledgment and removal.	• message circulated to receiver and removed; slot marked empty.	• read message address at receive register, divert to station or send to next register.
Comment	• this is a logical ring located on a bus; variable packet length.	• arbitrary packet length, simpler system than token bus.	• fixed packet length, depending on slot size.	• variable packet length not to exceed output buffer size.

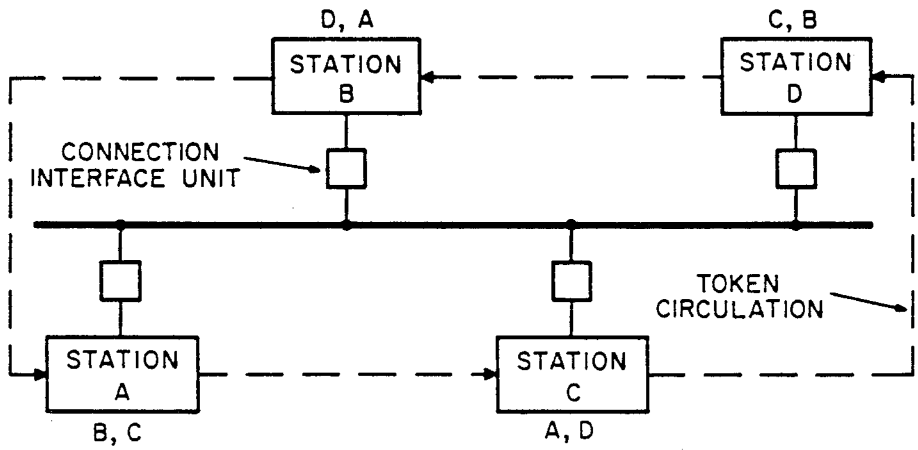


Figure 2-10. Token bus with preceding and succeeding addresses.

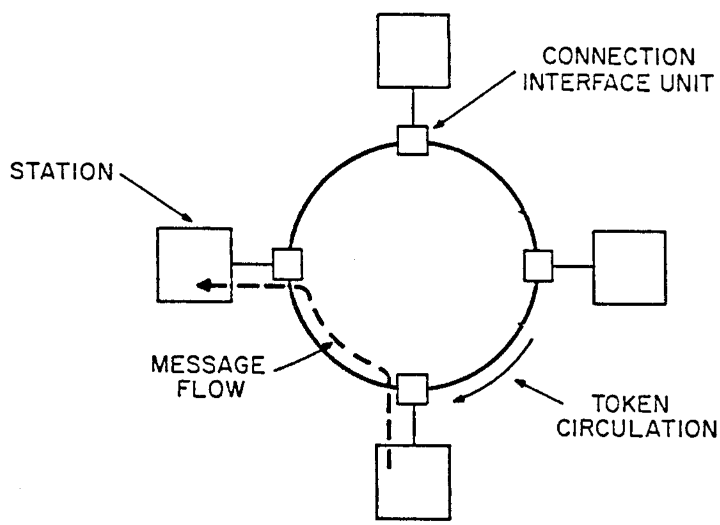


Figure 2-11. Token ring.

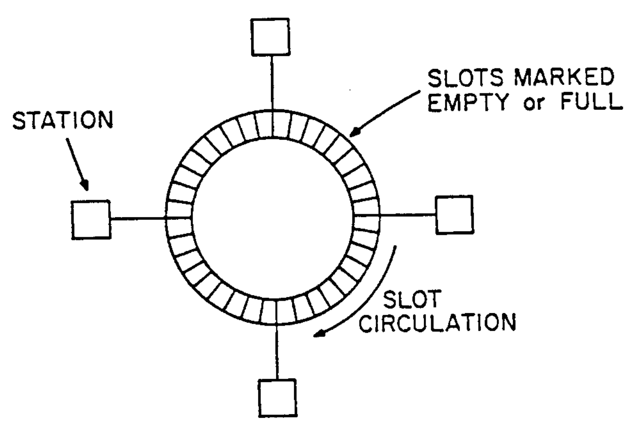


Figure 2-12. Slotted ring.

The register insertion ring, in turn, is a version of the slotted ring. There are two shift registers, input and output, at the interface to the transmission medium. The input shift register reads and stores incoming packets. The output register acts as a buffer, storing packets to be sent from the station. Packet size in both registers can be variable, but in either register, the packet size cannot exceed that of the buffer. The input register reads the packet address and,

1) diverts the message to the station if that is the address, or
2) forwards the address and message to the next node if it is not the station address.

When the input register is cleared,

1) it checks the output register to see whether a message is to be sent, and
2) determines whether there is a gap that exceeds the length of a waiting message. If the available slot bits exceed those of the message, the output buffer is emptied onto the ring in synchronism with any bit arrivals at the input register. Once the output buffer is emptied, the input register is cleared if it contains anything.

2.4 Combinations of Technology Choices

A summary of nominal combinations of local network technology choices is shown in Table 2-6. For the star topology, an analog and digital transmission with circuit switching is shown as it relates to PABX operation. Under Access Method, polling is shown for Star and Bus/Tree topology because it can be used for either configuration.

For basic local network concepts, there are three topologies, three types of media, and four access methods to consider for network design and selection. These are the star, bus, and ring topologies; the twisted-pair wire, coaxial (baseband or CATV), and fiber optic cable media; the circuit switching, polling, CSMA (CA or CD), and token passing access methods.

2.5 Performance

Local area networks that are most commonly available are based on two topologies and a limited number of medium access protocols:

Table 2-6. Combinations of Local Network Technology Choices

TECHNOLOGY CHOICES			
Topology	Transmission Technique(1)	Medium(2)	Access Method
Star	Analog, Digital	TPW, COAX, FOC	Circuit Switching Polling
Bus/Tree	Baseband, Broadband	TPW, COAX, CATV Cable	Polling CSMA/CA CSMA/CD Token Passing
Ring	Baseband	TPW, COAX, FOC	Token Passing

Notes: (1) Analog, digital transmission is associated with PABX operation. Baseband, broadband is associated with LAN operation.

(2) TPW = Twisted-pair wire
COAX = Baseband coaxial cable
CATV = Community Antenna Television cable
FOC = Fiber optic cable

- Bus topology
  - CSMA/CD
  - Token bus
- Ring topology
  - Token ring
  - Slotted ring
  - Register insertion

A paper by Stallings (1984a) summarizes the factors that are significant in determining LAN performance and studies that have been conducted to determine the performance of access protocols.

Performance in LAN's is determined by the medium access protocol and by two basic parameters that set an upper bound on performance, independent of the protocol. The two parameters are the data rate of the medium (R) and average signal propagation delay between stations (D). Their product determines the number of bits in transit between two stations at any moment. For example,

$$D = \frac{\text{length of medium (m)}}{\text{velocity of propagation(m/s)}} = \frac{l(m)}{v(m/s)}$$

if $l = 1000$ m and $v = 200$ m/μsec then $D = 5 \times 10^{-6}$ seconds

for R = 10 Mb/s (i.e., ETHERNET)

$$R \times D = (10 \times 10^{6} \text{ b/s})\ (5 \times 10^{-6}\text{s})$$

$$= 50 \text{ bits in transit between two nodes over a 1 km cable.}$$

Another parameter, α, represents the fraction of a frame that is exposed to a collision. The parameter for relative propagation delay is: $\alpha = \frac{RD}{L}$, where L = length of a data packet in bits. Some values of α in a bus network are shown in Table 2-7. A ring network would require that delays from repeaters be included in the propagation time since $\alpha = \frac{RD}{L}$ and $\frac{L}{R}$ is the time required for a packet to enter the medium from a transmitter.

Table 2-7. Values of α in a Bus Topology

Data Rate (R)	Packet Size	Cable Length	α
1 Mb/s	100 bits	1 km	.05
1 Mb/s	100 bits	10 km	.50
10 Mb/s	100 bits	1 km	.50
10 Mb/s	1000 bits	10 km	.50
50 Mb/s	1000 bits	1 km	.25
50 Mb/s	10000 bits	1 km	.025

In summary, for a bus,

$$\alpha = \frac{\text{Propagation delay (time)}}{\text{Message transmission time}},$$

$$= \frac{\text{Length of data path (bits)}}{\text{Length of data packet (bits/packet)}}, \text{ and}$$

$$= \text{Length of bus (packets).}$$

For a ring,

$$\alpha = \frac{\text{Latency}}{\text{Message transmission time}}.$$

Latency is the delay experienced in transmitting a bit completely around a ring; it is propagation delay of the ring plus processing delay at each interface on the ring.

This parameter α is then used to determine the maximum possible utilization (U) of a network, which is based on the following assumptions:

- there is one transmission at a time
- when one node stops sending, another node starts immediately
- there are no overhead bits to detract from performance

The derivation of U is as follows.

$$U = \frac{\text{Throughput}}{R}$$

$$= \frac{L/(\text{Propagation} + \text{Transmission time})}{R}$$

$$= \frac{L/(D + L/R)}{R}$$

$$= \frac{1}{1 + \alpha}$$

From this, the efficiency of utilization of a channel increases as α decreases. For an ideal case $\alpha = 0$, allowing 100% utilization of a channel. As α increases the utilization efficiency decreases as shown in Figure 2-13.

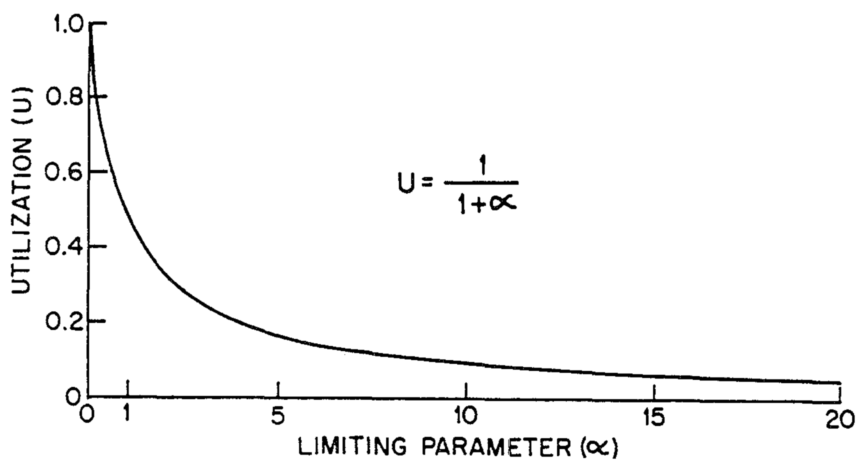


Figure 2-13. Local network utilization as a function of α.

As the efficiency of utilization decreases, the throughput (S) will decrease. This is unavoidable due to overhead bits (i.e., address and synchronization) and other unique overhead factors for the protocols. These factors include acknowledgment packets (CSMA/CD and token bus), the time a station waits for a token to arrive from stations with no data to send (token ring), the time a station waits for an empty slot to arrive (slotted ring), and the increased delay when registers at a station read each of the addresses (register insertion). Each of these increases α, thus decreasing throughput. Decreasing α is seen as desirable and it can be reduced by increasing packet length and/or reducing bus length.

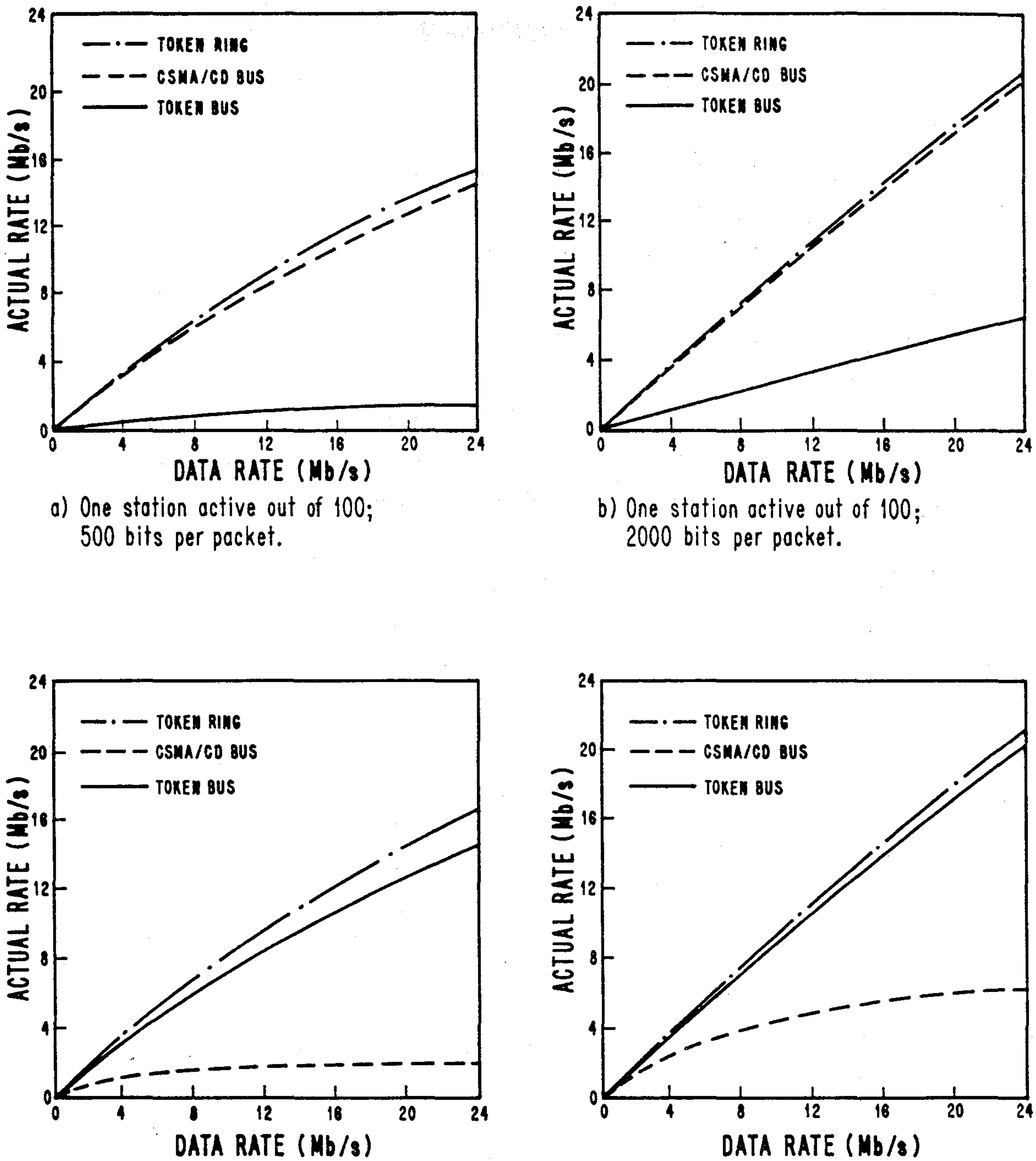
A number of studies show interesting results for the comparison of the CSMA/CD bus, token bus, and token ring. In a study conducted at Bell Laboratories and sponsored by the Institute of Electrical and Electronics Engineers (IEEE) 802 Local Network Standards Committee, the analysis resulted in a number of conclusions:

- CSMA/CD works best under a light load where traffic is likely to be sporadic or "bursty." It has the least delay with a light load and has increased delay with heavier workloads.
- Token ring is the least sensitive to changes in workloads.
- CSMA/CD has a strong dependence on α; as the packet length becomes smaller, the difference in the maximum mean throughput between token-passing and CMSA/CD becomes larger.

These conclusions are based on Figure 2-14. A number of conditions were set for the analysis. For the comparison, message statistics were changed by first setting one station out of 100 with messages to send, then setting 100 stations out of 100 with messages to send. In these extremes the results of the analysis show the maximum potential utilization of the network. Also, as shown in Figure 2-14, the packet length was set at 500 bits per packet and 2000 bits per packet for the two cases of station activity.

Figures 2-14a and b show the low throughput of a token bus compared to the token ring and CSMA/CD when only one out of 100 stations is active. This lower efficiency is attributed to the token (bus) passing time being assumed equal to the propagation delay and that delay exceeding that of a token ring. A study by Moraes and Rubin (1984) concludes that with respect to average message delay, token passing in a ring provides better performance than a bus, and that buses are more dependent on cable length than rings.

Figures 2-14c and d, show the problem with CSMA/CD, related to 100 active stations, and a comparison of short (500 bits) and long (2000 bits) packet lengths. The maximum mean data rate (throughput) remains relatively constant when the data rate is increased from 5 Mb/s to greater than 20 Mb/s. The CSMA/CD network cannot accommodate increased traffic (i.e., the actual rate) by raising the data rate. Here, the packet collisions increase in the CSMA/CD as the data rate is increased. Eventually all packets are being retransmitted, almost none get through, and the effective throughput becomes nil. This phenomenon is called "capture effect" and does not exist in the other protocols. Under light or heavy loading, the figures show improved CSMA/CD performance when the message packets are longer. Also shown is the relative stability of token ring operation for all conditions used in the analysis.



a) One station active out of 100; 500 bits per packet.

b) One station active out of 100; 2000 bits per packet.

c) 100 stations active out of 100; 500 bits per packet.

d) 100 stations active out of 100; 2000 bits per packet.

Figure 2-14. Maximum mean data rate for LAN protocols (Stuck, 1983).

A study (Liu et al., 1982) shows that in terms of delay and throughput analysis, the register insertion protocol is the best performer. Token passing is next, while CSMA/CD and slotted ring protocols depend on the parameters used in the network. Poor performance in the slotted ring can be attributed to high overhead in the bit slots and the time required to circulate empty slots of the ring. Register insertion has favorable utilization characteristics because 1) packets can be simultaneously transmitted from multiple stations and 2) transmission can take place when a gap opens on the ring. However, for $\alpha \ll 1$, for a heavy load, token ring operation is comparable to register insertion because data can be appended to a token at an adjacent station.

The performance characteristics that have just been described are based on analytical studies that give a reasonable comparison of the access protocols in question. However, in actual applications the real traffic would be at levels below maximum rates. The design requirements would specify traffic rates at levels below peak rates. Considerations such as this and analytical factors, such as 8-bit rather than 1-bit latency for a token ring, improve the relative performance of CSMA/CD. These factors, and lower installation costs per end-user, account for the relative popularity/availability of CSMA/CD.

3. STANDARDS

A significant effort has been expended over a period of several years to standardize local networks. The best known is that of the Institute of Electrical and Electronics Engineers (IEEE) Project 802. This effort is discussed in detail in this section.

Other local network standards activity to be discussed in this section is that of American National Standards Committee (ANSC) X3T9.5. They are developing, among others, the Local Distributed Data Interface (LDDI) and Fiber Distributed Data Interface (FDDI) as standards. The operation will be at 50 Mb/s and 70 Mb/s for the LDDI and 100 Mb/s for the FDDI. These standards specify a system bus to connect computers, peripheral subsystems, terminal concentrators, file servers, and gateways as peers.

Two military standards relating to local networks are MIL-STD-1553 and MIL-STD-1773. The 1553 was initially released by the Department of Defense in 1973 for use in the high-noise environment of military aircraft. The current 1553B version operates at 1 Mb/s on shielded twisted-pair wire. The

MIL-STD-1773 is a proposed data bus standard, also operating at 1 Mb/s, but using fiber optic cable. The development of 1773 has been with the intent of minimizing impact in a transition from 1553B to 1773. These are also discussed in this section.

3.1 IEEE 802

Standardization of local network protocols has been ongoing since February 1980 when the work on Project 802 was begun in the United States by the IEEE. The work in Project 802 is a family of six proposed standards intended to define a set of interfaces and protocols that permit user applications to be served by having a number of devices communicate with each other. The applications include file transfer, graphics, word processing, electronic mail, office automation, digital voice, and digital video. Data devices on the network are to include computers, terminals, mass storage devices, printers/plotters, and bridges and gateways to other networks.

The IEEE 802 work distinguishes between three types of networks: LAN's, Metropolitan Area Networks (MAN's), and Wide Area Networks (WAN'S). The standards are to apply to the first two networks, but not the third. The LAN's are for a restricted geographic area, such as a single office building, warehouse, campus, or military base. As defined, the LAN communication channel will operate at a moderate to high data rate (1 Mb/s to 20 Mb/s), and have a low delay with a low error rate. A single organization is expected to own a LAN. The MAN is for a larger geographical area than a LAN and is to cover several blocks--entire cities with distances to 50 km. Communication channels similar to those of the LAN are to be used, and although the MAN may be owned by one organization (e.g., a public utility), it would be used by many individuals and organizations. The WAN's provide communication capability in much larger geographic areas and interconnect facilities in different parts of the country.

There is an Executive Committee that oversees Project 802 operation, six working groups (802.1 through 802.6), and two technical advisory groups, 802.7 and 802.8 (IEEE, 1983a). Table 3-1 is a listing of the standards produced by the working groups and the status of their documents. The Broadband Technical Advisory Group (TAG) (802.7) is preparing a Recommended Practice/Guideline with the first draft scheduled for June 1985. The Fibre Optics Technical Advisory Group (802.8) provides advice to the other groups and is not preparing a standard. The TAG's do not produce standards.

Table 3-1. IEEE Project 802 Committees Standards and Status

IEEE STANDARD	TITLE	STATUS
802.1	Overview, Internetworking, and Management	Completion not projected.
802.2	Logical Link Control	Published, 1985.
802.3	CSMA/CD Access Method and Physical Layer Specifications	Published, 1985.
802.4	Token-Passing Bus Access Method and Physical Layer Specifications	Published, 1985.
802.5	Token-Passing Ring Access Method and Physical Layer Specifications	To be completed in 1985.
802.6	Metropolitan Network Access Method and Physical Layer Specifications	Initial Development.

The 802.1 document describes the relationship between the 802 standards and the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Reference Model. It also explains the 802 standards relative to higher layer protocols, internetworking, and network management issues (Figure 3-1).

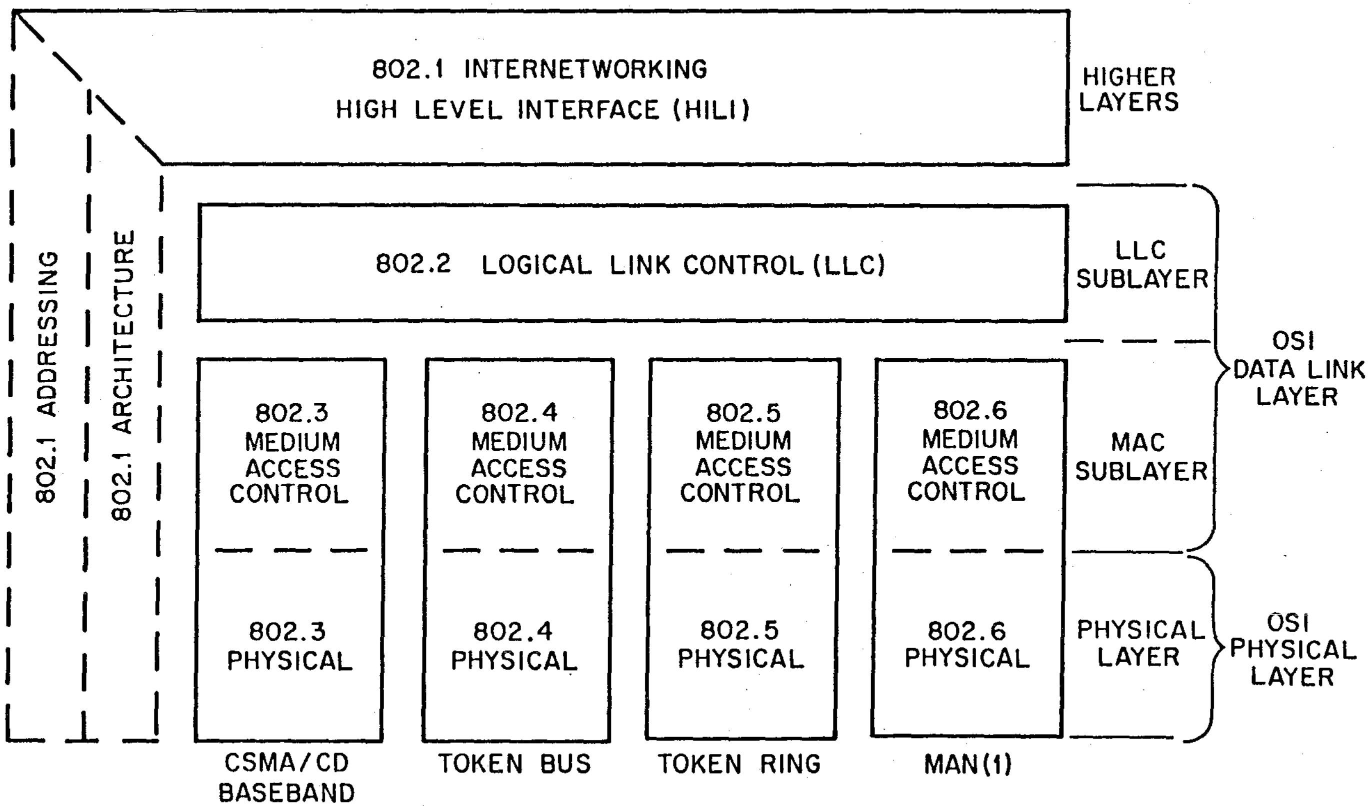
The 802.2 LLC document specifies protocols to control one or more logical links on a single medium.

The 802.3 standard, CSMA/CD, specifies an interconnection technique for stations to share access to a 50-ohm baseband coaxial cable bus.

The 802.4 token-passing bus standard specifies an interconnection technique for devices to share access on a bus topology, define protocols used by the physical layer and medium access control (MAC) sublayer, and relates to higher layers.

The 802.5 token ring standard specifies a point-to-point ring topology and a token passing access method.

The 802.6 MAN's will be used for operating at distances between 5 km and 50 km at data rates of 1 Mb/s or greater. This standard is in initial development and there is neither a draft available, nor a scheduled completion date.



(1) MAN- Metropolitan Area Network

Figure 3-1. IEEE 802 family of standards.

The work of IEEE 802 has created significant interest abroad, where similar work has been continuing within the European Computer Manufacturers Association (ECMA) and the ISO.

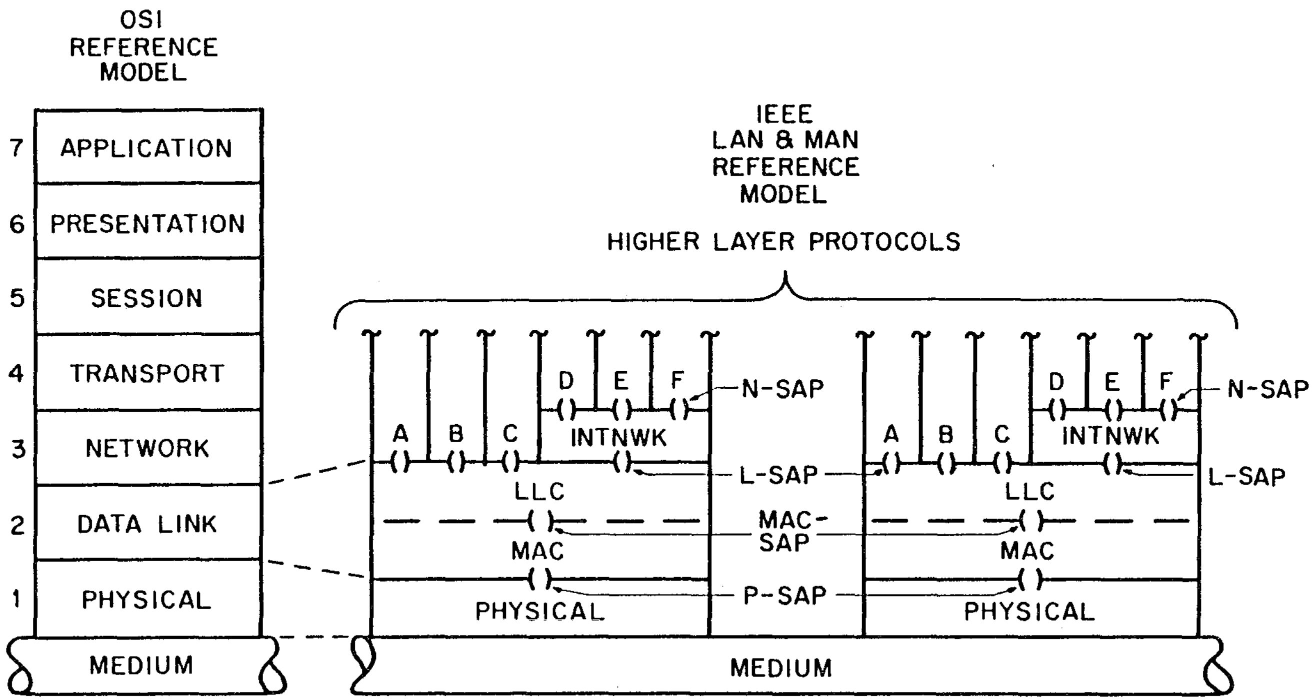
The ECMA has maintained close liaison with the IEEE 802 committee. As the draft standards were developed, the ECMA published earlier versions as implementation guides. As changes have been made by the IEEE 802, the ECMA has incorporated the new provisions in its standards so that alignment between the standards is maintained (Omnicom, 1984b).

The ISO Subcommittee 6, Data Communications, is also working on the IEEE 802 standards, with eventual approval and publication as international standards (Omnicom, 1984c). The ISO has assigned the number 8802 to the IEEE standards. The suffixes remain the same (e.g., 8802.1, 8802.2, etc.).

3.1.1 IEEE 802.1, Internetworking

The IEEE Draft Standard P802.1 (1983b) is work that is in progress without a projected date of completion (as of December 1984). This standard addresses a variety of issues such as internetworking, addressing, network management, and higher layer interfaces as defined in the International Organization for Standardization (ISO) Open System Interconnection (OSI) reference model (Appendix A).

The 802.1 work provides the framework for relating the OSI reference model to the Local and Metropolitan Area Network architectural model (Figure 3-2). The physical layer, and the logical link control (LLC) and medium access control (MAC) sublayers, are equated to the physical and data link layers of the OSI model. The physical layer is concerned with electrical signaling between peer units, the type of transmission medium to be used, the means of attaching devices to the medium and, as with all layers, provides services to the layer above it. The MAC sublayer, supported by the physical layer, provides access control to the medium in support of the LLC sublayer so that only one network device attempts to transmit at a time. The medium access that is used is unique to each method defined in the 802 standards, i.e., CSMA/CD, token bus, and token ring. The LLC sublayer is common to the various medium access methods (Figure 3-1). It is concerned with establishing, continuing, and disengaging a logical link connection between stations on a local network. Using the modular approach as articulated by the OSI reference model means that, for example, if a specification change is needed in a particular MAC, the implementation will affect only a limited part of the network. The entire system will not require modifications.



N-SAP: Internetwork Service Access Point
L-SAP: Logical Link Control (LLC) Service Access Point
MAC-SAP: Medium Access Control (MAC) Service Access Point
P-SAP: Physical Service Access Point
(from IEEE Draft Standard 802.1, Revision B, June 1983)

Figure 3-2. OSI and IEEE reference models.

Shown in Figure 3-2 are service access points (SAP's) that are located between the various layer and sublayer interfaces. Information is exchanged through primitives between entities within the layers that support services for enabling a communication. The primitives are interactions between the layers to convey a request, indication, response or confirmation. An entity is a function(s) within a layer that provides the services for a communication (Appendix A). The P-SAP provides an interface port between the physical layer and MAC sublayer. There are multiple interface ports at the top of the internetwork layer (N-SAPs) and at the top of the LLC sublayer (L-SAPs). There is one SAP between the LLC and MAC sublayers (MAC-SAP). Logically, three stations could be connected to the entities in the LLC sublayer through L-SAPs A, B, C.

This brief description of an abstract concept and Appendix A provide the basis for understanding the occurrences/interactions that are part of the OSI reference model as they are used in the development of IEEE 802 standards. Care should be taken when relating the 802 LAN LLC and MAC sublayers to the OSI data link layer. Controversy exists as to whether functions defined for the OSI network layer are performed at the LLC sublayer. This dichotomy is noted to inform the reader of ongoing differences in standards activity. No attempt is made in this report to rationalize the differences, merely to describe the current status of the standards. Another caution should be noted: many of the 802 LAN reference papers, although nearing completion, are working documents.

Networking is another integral part of IEEE Standard 802.1. A description and applications will be provided in Section 4.

3.1.2 IEEE 802.2, Logical Link Control

The IEEE Standard 802.2 (1983c), logical link control protocol standard is common to the four media access standards: 802.3, CSMA/CD; 802.4, token bus; 802.5, token ring; 802.6, Metropolitan Area Networks. It defines the services that will be provided by an entity within a layer to higher or lower (sub) layers and the protocols that will be used to control the logical connections of a number of stations to a transmission medium. The protocols are used to exchange information packets (primitives) between the layers through the SAP's in providing the services.

The LLC defines two types of services for data communication.

The first is the unacknowledged connectionless service, or Type 1 operation. Type 1 operation permits the exchange of information packets (Protocol Data Units, PDU's) without establishing a data link connection between LLC sublayers. There is no acknowledgment, flow control, or error recovery at the LLC sublayers. These functions may exist at higher layers. This operation has a minimum of protocol complexity and there is no relationship to past or subsequent data units. It is for quick, single-frame messages where guaranteed message delivery is not required. This is also called a datagram service and may be point-to-point, multipoint, or broadcast.

The second is the connection-oriented service, or Type 2 operation. In contrast to Type 1 operation, Type 2 requires that a data link connection shall be established between two LLC sublayers before an exchange of PDU's occurs. This operation provides for data unit acknowledgment, reset, termination, flow control, or error recovery at the LLC sublayers. The Type 2 operation uses a balanced link configuration, known as Asynchronous Balanced Mode (ABM), that is similar to, and not exactly the same as, ISO HDLC (ISO, 1983a; b) and American National Standard Institute ADCCP bit-oriented protocols (ANSI, 1979). The same ABM procedures provide the basis for CCITT X.25 (1980) Level 2, LAPB operation. The difference between LLC and the HDLC and ADCCP standards is in the division of data link layer addressing being located in separate MAC and LLC address fields (IEEE, 1983d).

Type 2 operation is only for point-to-point service.

There are two classes of LLC operation. A Class I LLC supports Type 1 operation only while a Class II LLC supports Type 1 and Type 2 operation.

There are four service primitives defined in the OSI reference model as shown in Figure 3-3a (Appendix A; ISO, 1982). Three of the four primitives are used in the LLC (Figure 3-3b); the response primitive is not used. A particular service is initiated at the LLC sublayer by the request primitive which is passed down from the next higher layer at the L-SAP (Figure 3-2). The "indicate" primitive is passed from the LLC back to the higher layer to advise that a particular service has been activated at a remote LLC. The "confirm" primitive is also passed upward to confirm that a particular service has been completed at the remote LLC.

The connectionless data service uses only two primitives across the interface: L_DATA.request asks that a data unit be transmitted and L_DATA.indication is used to pass a data unit up from the LLC (Figure 3-3c). Three service primitives are used for the connection-oriented service (Figure 3-3d).

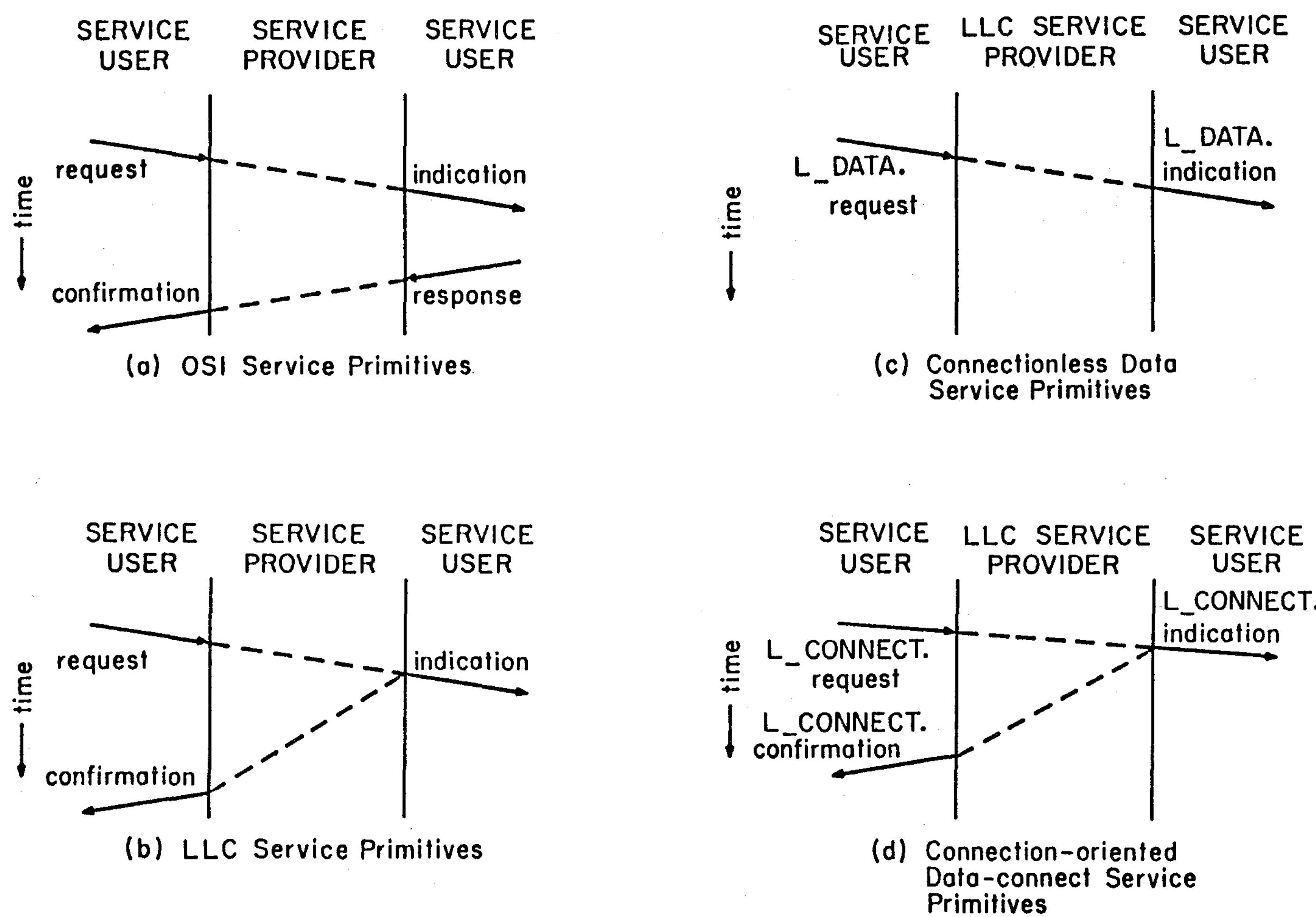


Figure 3-3. Examples of OSI and LLC service primitives.

A summary of the LLC primitives used for connectionless and connection-oriented service is summarized in Table 3-2. Each of the primitives conveys information in terms of parameters for remote and local addresses, control, and information fields. These four fields of the LLC frame are shown in Figure 3-4.

3.1.3 IEEE 802.3, CSMA/CD

The IEEE Standard 802.3, CSMA/CD (IEEE, 1982a), provides specifications for the medium access control (MAC) sublayer, and the physical layer (Figure 3-5).

The MAC sublayer provides support for the LLC sublayer; both are media-independent. Together the LLC and MAC are intended to have the same function as the OSI data link layer. Two main functions associated with the OSI data link layer are performed by the MAC. They are data encapsulation and decapsulation (to and from the LLC) including framing, addressing and error detection, and medium access management, which encompasses medium allocation and contention resolution--in summary, the CSMA/CD access protocol.

The 802.3 physical layer (Figure 3-5) consists of the following:

- the physical signaling (PLS) sublayer and attachment unit interface (AUI)
- the medium attachment unit (MAU) that is composed of the physical medium attachment (PMA) and medium dependent interface (MDI).

Operation of the MAC is described in 802.3 (IEEE, 1982a) for transmission and reception without contention and in the event a collision occurs. Referring to Figure 3-2, the following description of services would take place through primitives at the interface of the LLC and MAC sublayers (MAC-SAPs). Another set of primitives exists between the MAC and PLS sublayers (P-SAPs), and also between the PLS and PMA sublayers. The three basic service primitives are the request, the indication, and the confirm.

Figure 3-6 is used to describe collision-free and collision-detection actions within the MAC sublayer and interactions across interfaces with adjacent layers. Functional components within the sublayer (i.e., data capsulation and medium access management) perform the actions:

1) Normal Transmission Operation Without Collision.

   a) When the LLC sublayer requests the transmission of a frame, the Transmit Data Encapsulation component of the MAC sublayer constructs a frame from the LLC supplied data (MAC-SAPs). The frame has eight elements (Figure 3-7) and is handed to the next component in the MAC sublayer.

Table 3-2. LLC primitives.

Unacknowledged Connectionless	Connection-Oriented
L_DATA.request L_DATA.indication	• Connection-establishment L_CONNECT.request L_CONNECT.indication L_CONNECT.confirm • Connection-oriented Data Transfer L_DATA-CONNECT.request L_DATA-CONNECT.indication L_DATA-CONNECT.confirm • Connection Termination L_DISCONNECT.request L_DISCONNECT.indication L_DISCONNECT.confirm • Connection Reset L_RESET.request L_RESET.indication L_RESET.confirm • Connection Flow Control L_CONNECTION_FLOWCONTROL.request L_CONNECTION_FLOWCONTROL.indication

DSAP ADDRESS	SSAP ADDRESS	CONTROL	INFORMATION
8 BITS	8 BITS	y BITS	8×M BITS

DSAP address = destination service access point address field
SSAP address = source service access point address field
y = bits for sequencing, supervisory, command and response
8 bits for connectionless service
16 bits for connection-oriented service
Information = information field
M = integer value > 0 dependent on medium access control methodology used.

Figure 3-4. LLC Protocol Data Unit Format

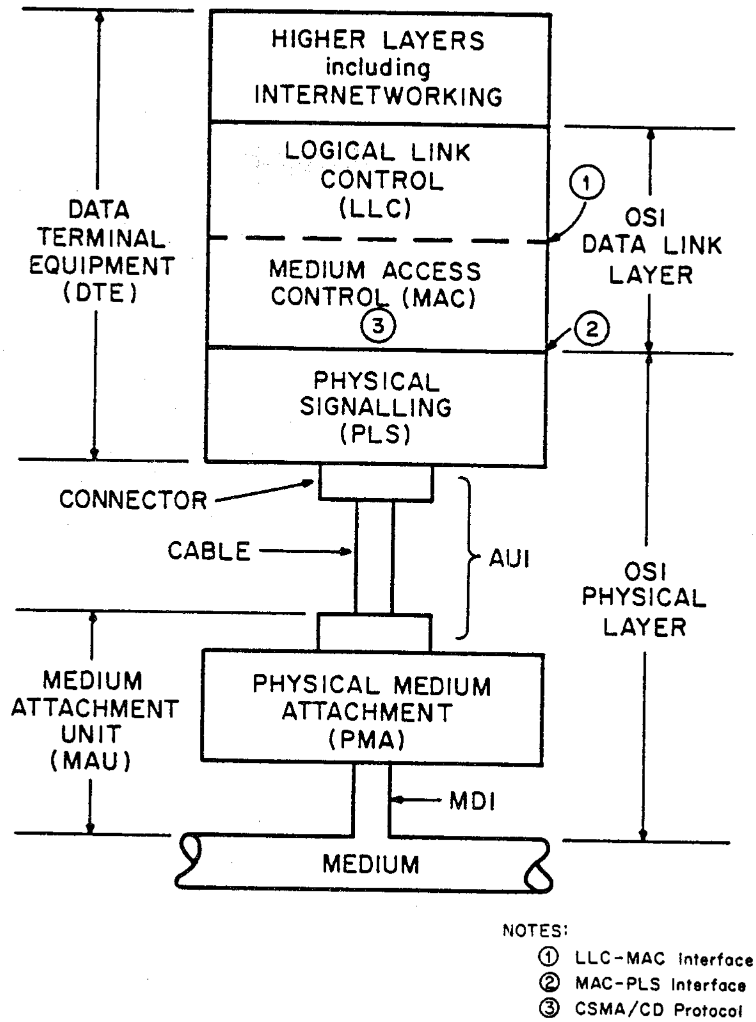


Figure 3-5. CSMA/CD implementation model.

Definitions:

PLS = Physical Signaling: that portion of the OSI physical layer within the DTE that provides the logical and functional coupling between the trunk cable medium and MAU.
AUI = Attachment Unit Interface: the cable, connectors, and transmission circuitry used to interconnect the PLS and PMA.
MAU = Medium Attachment Unit: contains the electronics that send, receive and manage the encoded signals impressed on the trunk cable medium.
MDI = Medium Dependent Interface: the mechanical and electrical interface between the trunk cable medium and PMA.
PMA = Physical Medium Attachment: that portion of the MAU containing functional circuitry.

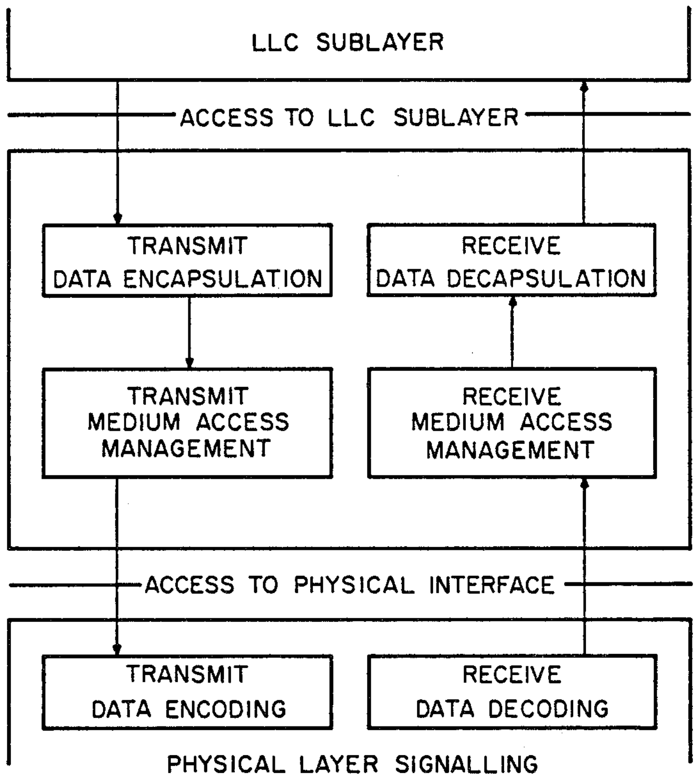
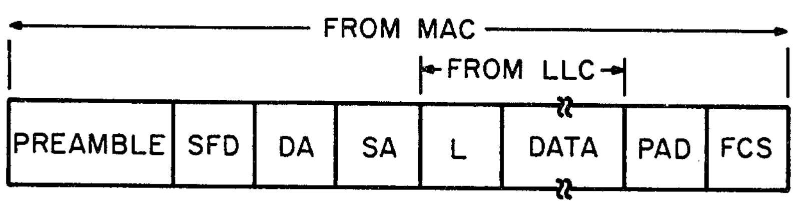


Figure 3-6. CSMA/CD medium access control functions.



PREAMBLE = physical medium stabilization and synchronization (7 octets)
SFD = Start Frame Delimiter (1 octet)
DA = Destination Address (2 or 6 octets)
SA = Source Address (2 or 6 octets)
L = Number of LLC data octets (2 octets)
DATA = LLC prepared data field
PAD = added octets to insure minimum frame size requirement
FCS = Frame Check Sequence (4 octets)
Low order bit transmission is first; FCS is the exception.

Figure 3-7. MAC frame format for CSMA/CD.

b) The Transmit Media Access Management component checks for contention with other traffic by monitoring the signal provided by the PLS and deferring to passing traffic. When the medium is clear, transmission is begun, and the MAC sends a bit stream to the PLS for encoding.

c) After transmission is completed without contention, the MAC sublayer notifies the LLC and awaits the next request for transmission.

2) Normal Reception Without Collision.

a) At each receiving station, the arriving frame is detected at the PLS, which synchronizes with the incoming preamble. The PLS turns on the carrier sense signal, decodes arriving bits, and passes them to the MAC sublayer where the preamble and SFD are discarded.

b) The Receive Media Access Management component collects bits from the PLS until the carrier sense signal is ended then passes data to the next component of the MAC sublayer.

c) The Receive Data Decapsulation checks the frame destination address field for the correct address and FCS. If correct, the entire data unit is sent to the LLC sublayer.

3) Collision Detection, Enforcement, Backoff, and Retransmission.

a) A collision occurs when two or more stations transmit at the same time. A collision window is the period when a station's transmitted signal has propagated to all stations on the CSMA/CD medium and the signal has propagated back without collision. Once this window passes, the station acquires immediate access to the medium, avoiding subsequent collisions when other stations defer. Acquisition time of the medium is based on the round-trip propagation time through the physical layer, including the PLS, PMA, and transmission medium.

b) If a collision occurs during the window period, the PLS turns on a collision detect signal. The Transmit Media Access Management then begins collision handling. First, to enforce the collision, it sends a bit sequence called the "jam" to ensure that the collision was noticed by all the other stations. (The period of twice the end-to-end propagation delay plus MAC jam time is called "slot time".)

c) After sending the jam signal, the Transmit Media Access Management terminates the transmission involved in the collision and schedules a delayed retransmission controlled by a random process called "truncated binary exponential backoff." This delay is an integral multiple of the slot time. Retransmissions are attempted in the face of repeated collisions until the frame transmission succeeds or is abandoned on the assumption that the medium has failed or is overloaded.

A problem with this CSMA/CD procedure is that the back-off period increases for "old" transmissions so that "new" transmissions have a better chance of getting through.

A summary of IEEE 802.3 CSMA/CD characteristics is shown in Table 3-3. Note that the contention method is 1-persistent, previously described in Section 2.3.3. The maximum number of repeaters is four. This extends the maximum distance between stations from 500 m to 2.5 km (Figure 3-8).

The 802.3 CSMA/CD standard is based on the Ethernet technique, which was originally developed by the XEROX corporation. A subsequent version was jointly developed by XEROX with Digital Equipment Corporation and Intel Corporation.

As of December 1984 there are five additional variations of 802.3 standards under consideration by the IEEE committee (EEM, 1984a). They are summarized in Table 3-4.

Table 3-3. CSMA/CD Characteristics

Access Method	CSMA/CD
Contention	1-persistent
Topology	Bus
Modulation	Baseband/Digital
Coding	Manchester
Data Rate (Mb/s)	1, 5, 10, 20
Medium	50-ohm coaxial cable
Max. Length of Coaxial Segments	500 meters
Max. Number of Taps/Segment	100 Medium Attachment Units (MAU)
Max. Number of Repeaters	4 between stations (see Figure 3-8)
Max. End-User Distance	2.5 Km

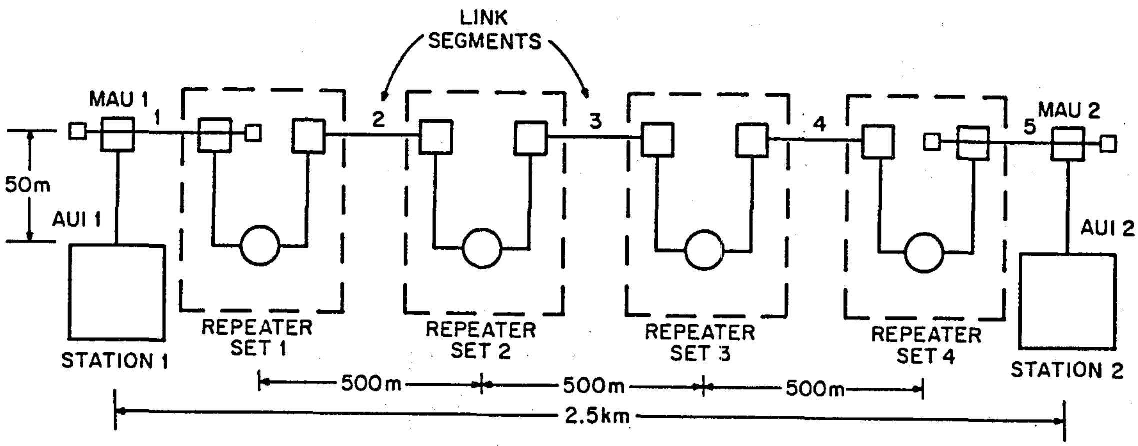


Figure 3-8. Maximum distance between two CSMA/CD stations.

Table 3-4. IEEE 802.3 CSMA/CD Variations

SYSTEM	MODULATION	DATA RATE (Mb/s)	MEDIUM
• CHEAPERNET	BASEBAND	10	CHEAPER COAX
• ATTACHMENT UNIT INTERFACE (AUI)	BROADBAND	10	CATV COAX
• FIBER-OPTIC INTER-REPEATER LINK (IR)	LIGHTWAVE MODULATION	10	OPTICAL FIBER
• STAR-LAN	BASEBAND	1	TWISTED-PAIR WIRE
• OPTIMIZED BROADBAND	BROADBAND (FSK)	2	CATV COAX

The Cheapernet, the Attachment Unit Interface (AUI), and Fiber-Optic Inter-Repeater Link are plug compatible variations of 802.3. Cheapernet allows an inexpensive coaxial cable (RG-58) to be used instead of a more expensive, highly shielded cable. The AUI allows an rf modem to be used to transmit over a CATV coaxial cable. The Fiber-Optic Inter-Repeater Link is to be used to interface between 802.3-compatible repeaters to connect separate local networks.

The Star-LAN and Optimized Broadband have significant differences from the 802.3 standard. Star-LAN uses shielded twisted-pair wire for 1 Mb/s operation in a short-bus application. A short bus would use CSMA/CD in a star-shaped local network to connect user devices. Optimized Broadband is a long-distance (10 km), broadband version of 802.3. It is based on work that has been done for an IBM Personal Computer local network by Sytek, Incorporated.

3.1.4 IEEE 802.4, Token Bus

The IEEE Standard 802.4, token-passing bus (IEEE, 1982b), provides specifications for the MAC sublayer of the OSI data link layer, the physical layer, a station management function that interfaces with the MAC and physical layers, and the attachments to the physical medium (Figure 3-9). (A brief description of token bus operation is given in Section 2.3.3.)

The 802.4 MAC sublayer determines sequential access to the bus medium and passes controls of the medium from station to station. The MAC determines medium access by recognizing and accepting the token from a predecessor station and passing it to a successor station.

The LLC-MAC interface of the token bus provides for connectionless data transfer services between peer LLC entities (also see Section 3.1.2). The LLC service data units can be exchanged on a point-to-point or multipoint basis.

The 802.4 physical layer supports the MAC sublayer by the sending and receiving of symbols with a duration of one bit period. This is the means by which peer-to-peer MAC protocols coordinate and exchange information across a shared medium.

The station management entity interfaces with the MAC sublayer and physical layer. Local administrative services are accounted for across the LLC and MAC interfaces. These include services such as resetting the MAC entity, address and protocol selection, protocol confirmation, setting of timer periods (e.g., slot time) and specifying addresses to be recognized. Across the station management-physical layer interface, the services include:

- resetting the physical layer entity and local network topology with appropriate protocols (e.g., token bus or token bus repeater)
- selection and notification of operating modes. These modes include transmit and receive channel assignments, adjustment of transmitted signal levels, and reporting of received signal levels.

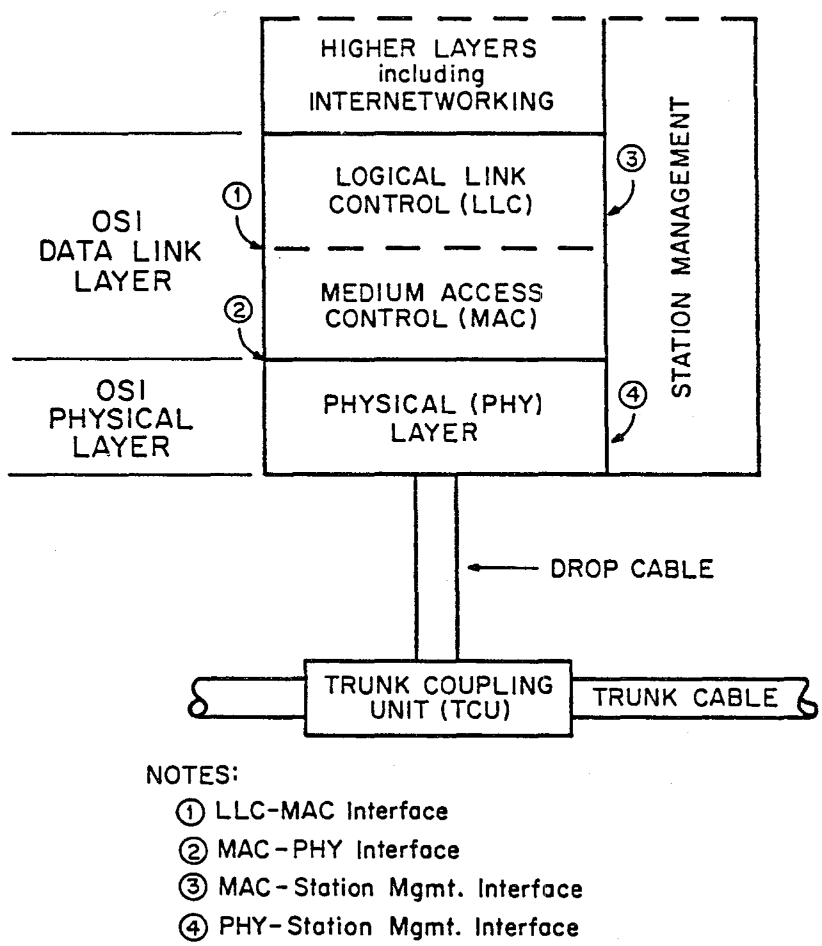


Figure 3-9. Token bus implementation model.

The MAC sublayer is divided to perform ten general functions. They include:

- Lost token timer
- Distributed initialization
- Token holding timer
- Limited data buffering
- Station address recognition
- Frame encapsulation
- FCS generation and checking
- Valid token recognition
- New ring member addition
- Node failure error recovery

The functions are performed in the MAC sublayer by five asynchronous logical machines. A possible partitioning is shown in Figure 3-10.

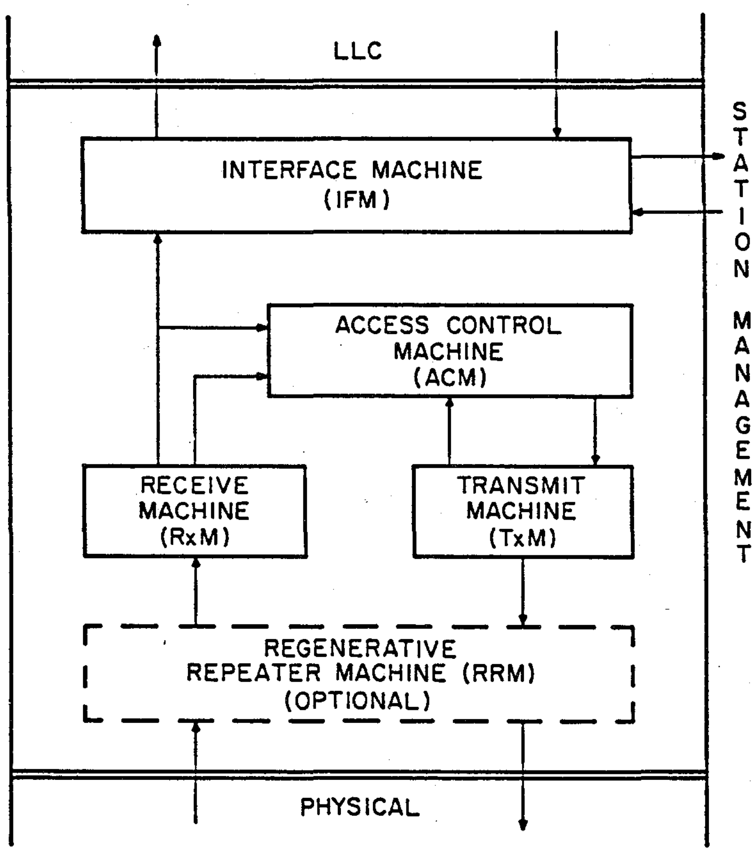


Figure 3-10. Functional partitioning in the MAC sublayer.

The Interface Machine (IFM) acts as interface and buffer in the MAC sublayer to the LLC sublayer and to the Station Management. It maps "quality of service," handles queuing of service requests, and performs address recognition for frames going to the LLC.

The Access Control Machine (ACM) is the crux of the MAC sublayer. It cooperates with the ACM's of all other stations on the medium in handling the token to control access. The ACM is responsible for maintenance of the logical ring (i.e., admission of new stations) with detection and recovery from network failures.

The Receive Machine (R x M) accepts symbols from the physical layer. It assembles the symbols into frames, checks the structure, and conveys them to the IFM and ACM.

The Transmit Machine (T x M) accepts data frames from the ACM for transmission, in the proper format, to the physical layer.

The Regenerative Repeater Machine (RRM) is an optional component that is used only in special "repeater" stations such as a broadband, head-end remodulator. In a repeater configuration, the RRM repeats the bit stream coming from the physical layer back to the physical layer.

Operating and formal descriptions of these machines are given in the IEEE standard (1982b) for 802.4. A brief description of the ACM is given here because of its importance to token bus operation.

There are eleven computational sequences or phases called states in the ACM.

1) Unpowered. The unpowered state precedes the power-up state. When powered, the station performs a self-test, including a connection to the medium, without transmitting to other stations.

2) Idle. The station listens to the medium during the idle state but does not transmit.

3) Demand In. This state is entered when a solicit-successor frame is received at a station desiring entry into the ring. During the Demand In state the contending station sends a set-successor frame to the token holder. A station returns to the idle state if it hears any transmission and assumes that a higher numbered address is requesting the token.

4) Demand Delay. This state is entered by the station after sending the set-successor frame. The following actions may occur:

a) The token holder sends the token to the soliciting station, contention resolution is over, and the soliciting station can transmit.

b) The token holder hears from several stations and sends a resolve contention frame. A resolution process takes place where the highest addressed station has priority to receive the token.

c) Set-successor frames from other stations may be heard by the soliciting station. These are ignored.

5) Claim Token. The claim token state is entered from the idle state. Claim tokens are sent during slot times by stations wishing to be part of the access ring. The logical path is (re)initialized allowing the station to enter the ring.

6) Accept Token. The station enters this state after receiving or claiming a token. A station can remove itself from the ring by sending a set-successor frame, with the address of its successor, to the preceding station.

7) Use Token. Data frames can be sent. A token-holding timer is set by the station. This limits the transmission period until the token must be passed along.

8) Check Access Class. This state offers a priority option where high priority frames are sent first. If not implemented, all frames are considered high priority.

9) Pass Token. When sending is complete a station may or may not transmit a token to its successor. If it knows its successor, it can pass the token and enter the check token pass state, or it can check for new stations by sending a solicit-successor frame and enter the await response state. If the station does not know its successor (i.e., after initialization) a solicit-successor frame is sent, opening response windows for all stations, then the station enters the await response state.

10) Check Token Pass. In this state the station awaits a reaction from the station that received the token. The token-sending station waits one slot time for the token-receiving station to send. The slot time is the delay period during which a recipient receives a frame and responds.

a) A token pass is successful if a valid frame is heard and processed as if it were an idle state.

b) A token pass is assumed unsuccessful if nothing is heard in one slot time. A return is made to the pass token state.

11) Await Response. The await response state is entered from the pass token state. The station attempts to sequence successor stations through a distributed contention resolution algorithm where a response window is opened. The station, which is holding a token, waits for a number of response window times. If nothing is heard, the station goes to the pass token state then goes through the procedures of that state.

The frame structure sent by the MAC sublayer is shown in Figure 3-11.

PREAMBLE	SD	FC	DA	SA	DATA_UNIT	FCS	ED

PREAMBLE = pattern sent to synchronize receiver (1 or more octets, depending on data rate)

SD = Start Delimiter (1 octet)

FC = Frame Control (1 octet)

DA = Destination Address (2 or 6 octets)

SA = Source Address (2 or 6 octets)

DATA_UNIT = Information (0 or more octets)

FCS = Frame Check Sequence (4 octets)

ED = End Delimiter (1 octet)

- There shall be 8191 or fewer octets between SD and ED.
- Lowest order bit transmission is first.

Figure 3-11. MAC frame format for token bus.

A summary of the IEEE 802.4 token bus characteristics is shown in Table 3-5. Note that while there is one access method there are single and dual channel transmission options based on three modulation schemes: phase continuous FSK, phase coherent FSK, and multilevel duobinary AM/PSK. The implementation costs would be lowest for the phase-continuous FSK; it can carry only one signal in its channel. The highest implementation cost would be for the full broadband, multilevel duobinary AM/PSK using frequency division multiplexing for data and video transmission. The conventional North American CATV nomenclature is specified in the standard with recommendations for midsplit or subsplit operation. The 1.5 MHz channels are formed by equally subdividing any given 6 MHz channel. The 12 MHz channels are composed of adjacent 6 MHz channels.

Table 3-5. Token Bus Characteristics

Characteristic	Modulation Methods		
Access Method	Token	Token	Token
Topology	Bus	Bus	Bus with head end repeater
Channel operation	Single	Single	Multiple
Modulation	Broadband-Phase continuous FSK with differential Manchester	Broadband-Phase coherent FSK	Broadband-Multilevel duobinary AM/PSK
Signaling frequency	6.25 MHz/3.75 MHz	5 MHz/10 MHz 10 MHz/20 MHz	
Data Rate	1 Mb/s	5 Mb/s, 10 Mb/s	1 Mb/s in 1.5 MHz 5 Mb/s in 6 MHz 10 Mb/s in 12 MHz
Medium:			
Trunk	75-ohm coax	75-ohm coax	75-ohm coax
Drop	50-ohm coax	75-ohm coax	75-ohm coax

The phase coherent FSK can be upgraded to the highest cost implementation option.

Regenerative repeaters can be used with any of the three methods to extend operating distance.

An example of a commercially available 802.4 token bus LAN is the Token/Net™ from Concord Data Systems. It is designed to specifications of the duobinary AM/PSK modulation standard. The operation is on standard CATV broadband cable with six - 6 MHz wide channels. The data rate is 5 Mb/s per channel.

Enhancements to the 802.4 standard are being considered to accommodate PROWAY, an LAN intended for process control in an industrial environment.

3.1.5 IEEE 802.5, Token Ring

The IEEE Standard 802.5, token-passing ring (IEEE, 1984a) provides specifications for the MAC sublayer, the physical layer, a network management function that interfaces with the MAC and physical layers, and the attachment to the ring's physical medium (Figure 3-12). The trunk cable is subject to further study as of December 1984.

The 802.5 MAC sublayer controls and mediates access to the ring. The LLC-MAC interface of the token-passing ring access method provides for connectionless data transfer services between peer LLC entities (see Section 3.1.2). The physical layer is responsible for interfacing with the medium, detecting and generating signals on the medium, and converting and processing signals received from the medium and the MAC layer. The network management interfaces with all the layers of the station and is responsible for the setting and resetting of control parameters, obtaining reports of error conditions, and determining if the station should be connected or disconnected from the medium.

The following description of frame transmission and reception provides an overview of token ring operation, including normal and priority operation, and notification procedures on a network if a station fails. A token ring configuration where station B has been by-passed is shown in Figure 3-13. The by-pass function is available in case of station failure. It takes place in the trunk coupling unit (TCU). The first four steps that follow describe normal operation.

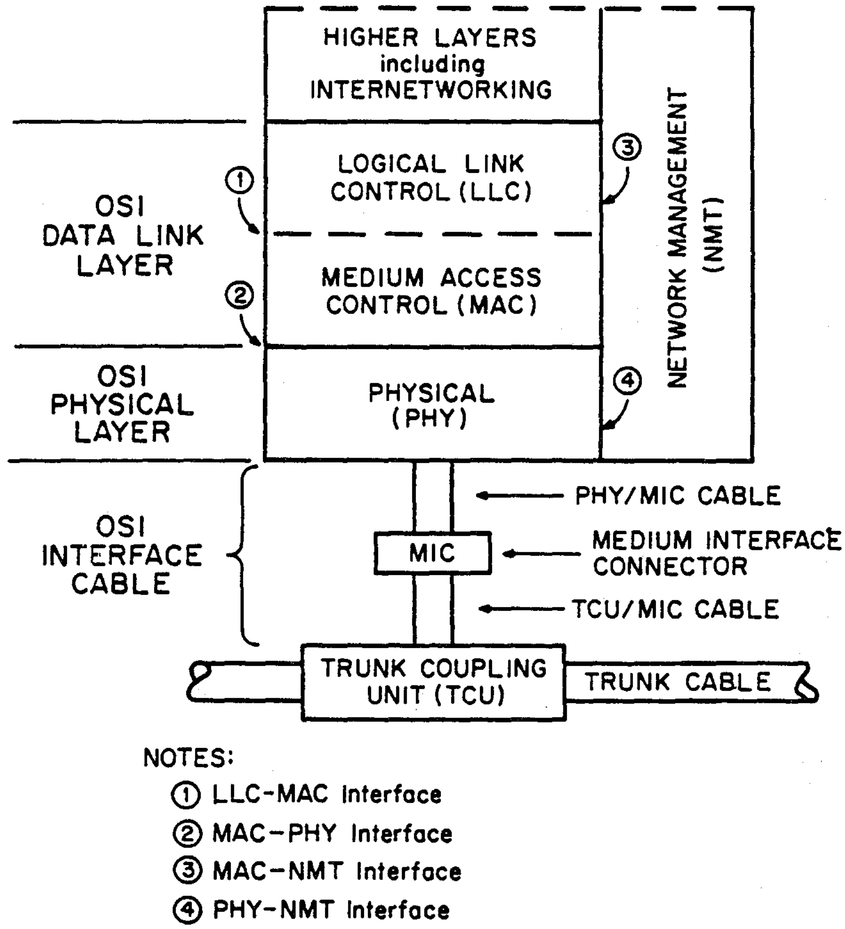
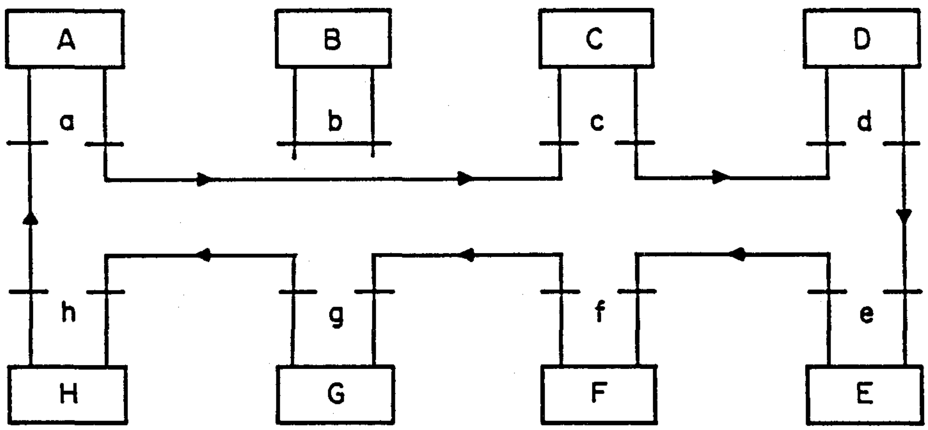


Figure 3-12. Token ring implementation model.

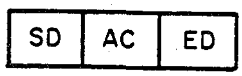
1) Frame Transmission. Access to the physical medium is controlled by passing a token (Figure 3-14a) around the ring. Priority to send is set by access control (AC) of the token. When a protocol data unit (PDU) is received from the LLC or Network Management (NMT), the frame control (FC), the destination address (DA), and source address (SA) are attached (Figure 3-14b).



A,B,C,D,E,F,G,H — Ring Stations   Physical Medium
a,b,c,d,e,f,g,h — Bypass Function
All stations are active except B (b illustrated in bypass mode)

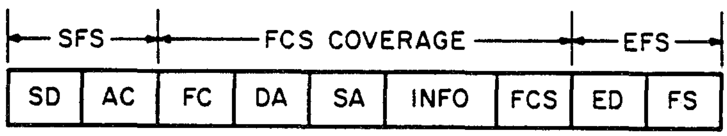
Figure 3-13. Token ring configuration.

This station then awaits the reception of a free token that may be used for transmission. The token priority is equal to, or less than, the priority of the PDU to be sent. Upon receipt of a usable token, the AC field of the token is changed (busy token) to a start of frame sequence, the station stops repeating the incoming signal and starts sending a frame. During this transmission, the frame check sequence (FCS) is appended to the information field.



*SD = Starting Delimiter (1 octet)
*AC = Access Control (1 octet)
ED = End Delimiter (1 octet)

a) Token frame format.



SFS = Start of Frame Sequence
*SD = Starting Delimiter (1 octet)
*AC = Access Control (1 octet)
FC = Frame Control (1 octet)
DA = Destination Address (2 or 6 octets)
SA = Source Address (2 or 6 octets)
INFO = Information (0 or more octets)
FCS = Frame Check Sequence (4 octets)
EFS = End of Frame Sequence
ED = Ending Delimiter (ED)
FS = Frame Status (FS)

- Most significant transmission is first; other 802 standards have the least significant bit sent first.
- MAC and LLC messages are sent to the destination station(s) using the information frame format.

* Octets common to token and information frames.

b) Information frame format.

Figure 3-14. Token and information frame formats.

2) Token Transmission. Upon completing frame transmission, and receiving the source address, the transmitting station sends a token to be used by the next station with data to send.

3) Stripping. After transmission of the token, the station remains in transmit state until all of the frames that were originated by the station are removed by the same station.

4) Frame Reception. As the signal stream is repeated by each station, a check is made to determine whether frames should be copied. If a MAC frame is indicated, and the destination address matches that of the station, the FC, DA, SA, INFO, and FS fields are copied into a receive buffer for forwarding to the appropriate sublayer. Frame removal by the source station allows broadcast operation and acknowledgment that the data has made one trip around the ring.

5) Priority Operation. There are three priority bits (PPP) and three reservations bits (RRR) within the AC field of the circulating token. Together these bits are coordinated to match the service priority of the ring to the highest priority of a PDU that is ready to be sent by a station on the ring. The SD and AC fields of the token and information frame formats are the same, except that a "T" token bit identifies each with a "0" or "1", respectively. At any given time, the operating priority level of the ring is defined by the existing token. For a station to transmit, a free token is needed where the priority level is less than, or equal to, that of the data unit (PDU) that is ready to be sent by a station. When the station transmits its information frame, the other stations read the RRR bits. Successive stations raise the RRR bits to their priority level, thus reserving the next token for the highest priority data to be sent. The PPP bits are set from the RRR bits. A station that has raised the service priority stores the old priority level in a stack called S_r. This is used for comparison with the new priority stored in stack S_x. Each stack, S_r and S_x, may have a series of priority levels. This information is used to resolve contention and restore ring operation to a lower service level when the transmission of an information frame is completed. When information frame transmission is complete, a new "free" token is issued with the highest priority service set in the PPP bits. A lower priority station cannot seize this token. Thus, the PPP bits state what the current service priority is, while the RRR bits reflect reservation requests of the highest priority data unit waiting to be sent.

6) Beaconing and Neighbor Identification. A detected failure in a token-ring network must be isolated so that recovery actions can take place. A failure domain is established. It consists of

a) the station downstream and reporting the failure (the beaconing station),

b) the station upstream from the beaconing station, and

c) the ring medium in between the stations.

The upstream neighbor identity is required for accurate problem determination. The frame status field (FS) of the information frame is used for neighbor notification. This FS field is read and if certain bits are zero, it regards the frame as having originated at the upstream neighbor. This process proceeds in a daisy-chain fashion until each station is aware of the upstream neighbor's identity. This information originates within the MAC sublayer.

A station that is designated as the active monitor ensures that the network is operating properly. Other stations are designated as standby monitors. Through MAC protocols, error recovery and fault isolation are consummated, and additional stations are brought on-line in the network.

A summary of IEEE 802.5 token ring characteristics is shown in Table 3-6. Complete physical layer characteristics remain to be determined. At present 802.5 specifies baseband operation using shielded twisted-pair 150-ohm wire for coupling to the trunk cable. Data signaling rates are 1 or 4 Mb/s.

Table 3-6. Token Ring Characteristics

Characteristic	Descriptor
Access Method	Token Passing
Topology	Ring
Modulation	Baseband
Data Rate	1 Mb/s or 4 Mb/s and higher rates
Coding	Differential Manchester
Drop Cable	Twin 150-ohm twisted-pair wire
Trunk Cable	To be determined (e.g., shielded twisted-pair wire, coaxial cable, fiber)
Stations/ring	>250

It is expected that the IBM token ring LAN that is anticipated (and using the cabling plan described in Section 2.2.4) will adhere to the IEEE Standard 802.5 specifications. A European firm claims that the token access method in the draft standard is the subject of U.S. patent number 4,293,948 and patents in other countries. The IEEE takes no position on the claim. It is reported IBM paid over $5 million for a license to use the technology several years ago (Bartik, 1984).

An example of a token ring network wired in a star-shaped ring, that is currently available, is the Proteon, Inc., proNET™ network. It offers 10 Mb/s operation. Duplex paths between stations may be implemented with twisted-pair wire to 100 m, twinaxial cable to 300 m, or fiber cable to 2.5 km. Up to 255 users can be supported by each ring. It will adhere to IEEE standards when 802.5 specifications are completed (Private communication, Proteon, December 1984).

3.1.6 IEEE 802.6, Metropolitan Area Networks

The IEEE 802.6, Metropolitan Area Network (MAN) Standards, will be used for operating over distances of 5 to 50 kilometers at data rates of 1 Mb/s or greater. This standard is in its initial stages of development. It does not have a scheduled completion date.

Subsequent to the IEEE 802 standardization effort for LAN's which was started in 1980, another group was appointed to work on network standards for metropolitan areas. The work was to go beyond the distance limitations of the CSMA/CD, token bus, and token ring networks. Initial work for a standard was based on a Time Division Multiple Access (TDMA) protocol similar to those used to communicate with satellites from multiple ground stations. This effort did not mature.

A new effort was started based on high- and low-speed bursty (e.g., LAN interconnection and interactive transactions) and nonbursty applications such as video, multiplexed voice, and conventional data communication. A number of responses were received by 802.6, including a proposal for a polling system. Station polling would be done in order of increasing distance, thus avoiding delays while waiting for a reply before sending another poll. Efficiency of throughput is improved by distance ordering and using several polling lists.

This system appears satisfactory for lower-performance applications such as small business communication. The work has centered on CATV coaxial cable as a transmission medium since it already exists in most cities although fiber-optic systems appear to have advantages for the future (IEEE, 1984b).

3.1.7 IEEE 802 Standards Summary

A summary of IEEE 802 standards, characteristics, and their relation to the LAN reference model is shown in Figure 3-15 (after Stallings, 1984b). Within the 802.5 specification, higher data rates of 4 Mb/s to 40 Mb/s may be provided with baseband coaxial cable. Fiber-optic cable is expected to be defined in the future as part of the standard.

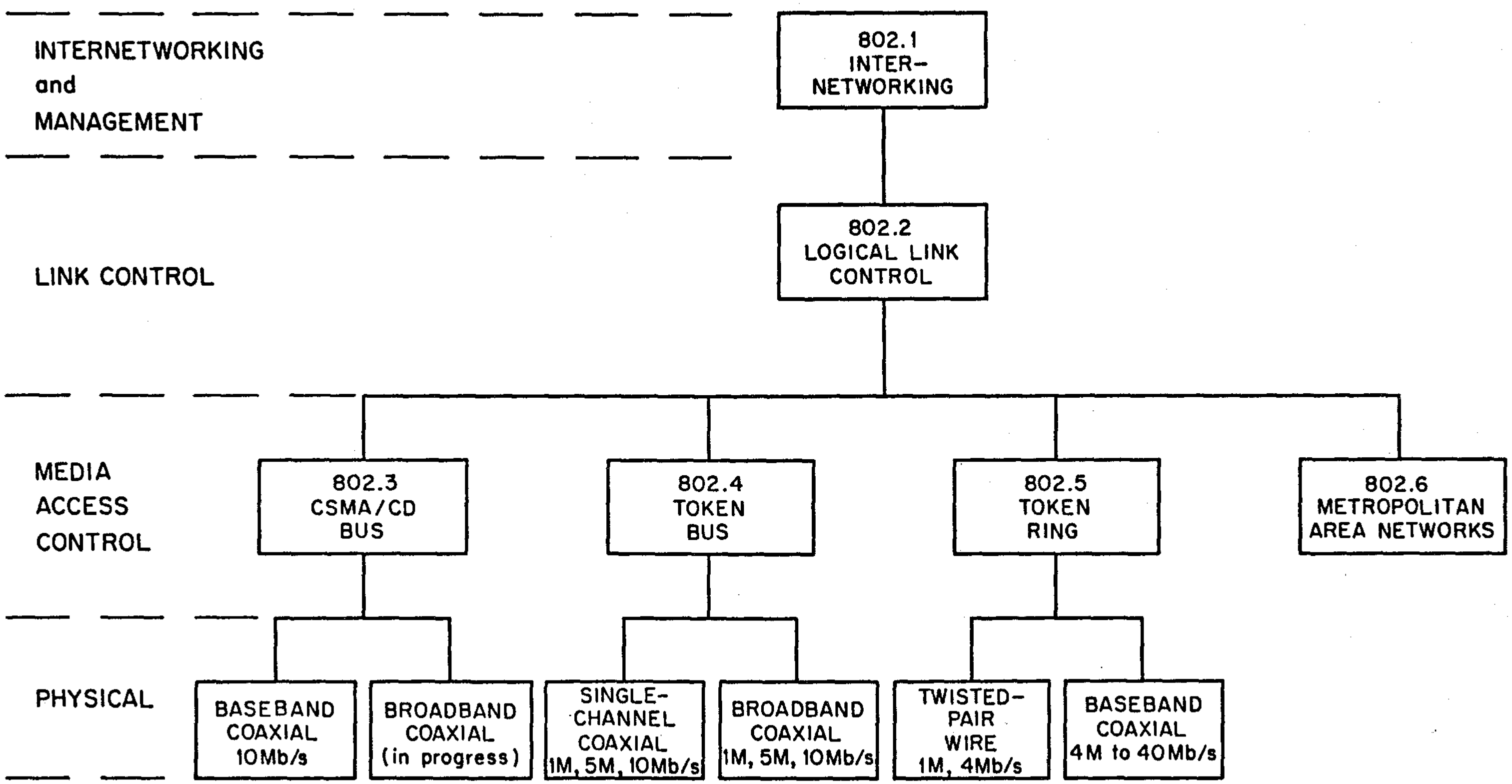


Figure 3-15. Summary of IEEE 802 standards and characteristics.

3.2 ANSC X3T9.5

The American National Standards Committee (ANSC) X3T9 has been developing standards for the Local Distributed Data Interface (LDDI) and Fiber Distributed Data Interface (FDDI). The LDDI describes protocols for use in high-speed (~70 Mb/s) local networks connecting computers, block data transfer disk and tape peripherals, terminal concentrators, and gateways. It encompasses the lower network-specific sublayer of the network layer and the data link and physical layers of the OSI reference model (X3T9.5, 1984a). The FDDI is intended for use with even higher performance (~100 Mb/s) local networks capable of connecting a number of super-computers and mass storage devices. It too, will eventually encompass a network sublayer, the data link layer, and physical layers of the OSI reference model (Burr, 1984). There are a number of significant differences between the LDDI and FDDI such as access methods, topology, modulation, and protocol techniques.

3.2.1 Local Distributed Data Interface

Very high data transfer rates can be performed using parallel bus interfaces. However, parallel interfaces are not satisfactory for distances that exceed 200 m because of differences in signal propagation rates (Burr, 1983). The X3T9 committee decided to develop a standard based on the advantages offered by serial, high speed local networks with busses of 1 km. The committee also decided to follow the ISO reference model for open system interconnection (Appendix A) in developing the interface standards at the physical and data link layers, but subsequently realized the need for work at the network layer. However, standards at this level are still to be developed (as of December 1984).

The initial work of the X3T9.5 (a task group of X3T9) developed an LDDI using a 1 km bus for connecting the computers, disks, and tapes (Figure 3-16). This has changed so that an LDDI now encompasses standards for a passive star topology with coaxial cables connecting subsystems to a central hub (Figure 3-17) in addition to the linear bus (X3T9.5, 1984a).

The OSI network layer has the Internet Protocol (IP) for the highest sublayer. It is concerned with the interconnection of dissimilar networks and is not network specific. The lowest LDDI network sublayer is network dependent and is concerned with routing, buffering, and error recovery (Figure 3-18).

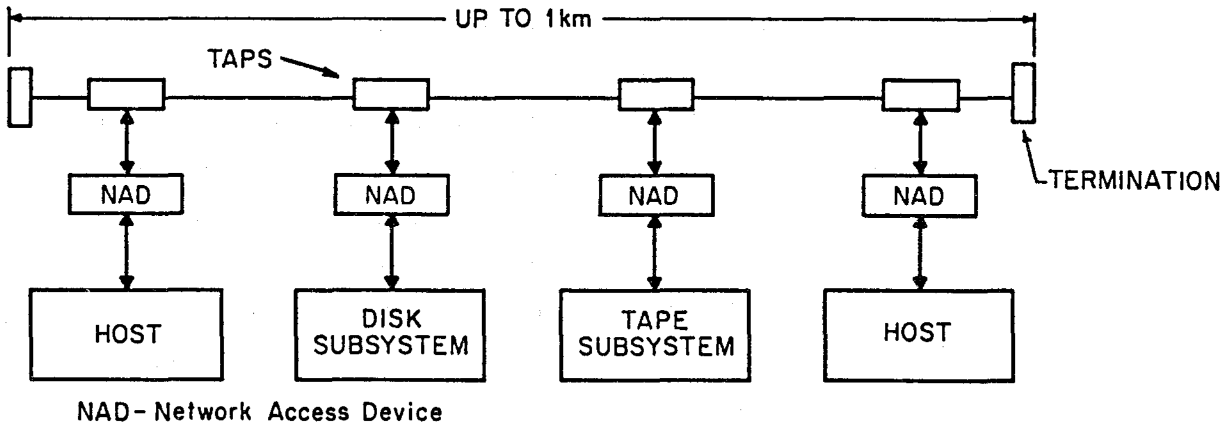


Figure 3-16. LDDI with linear bus.

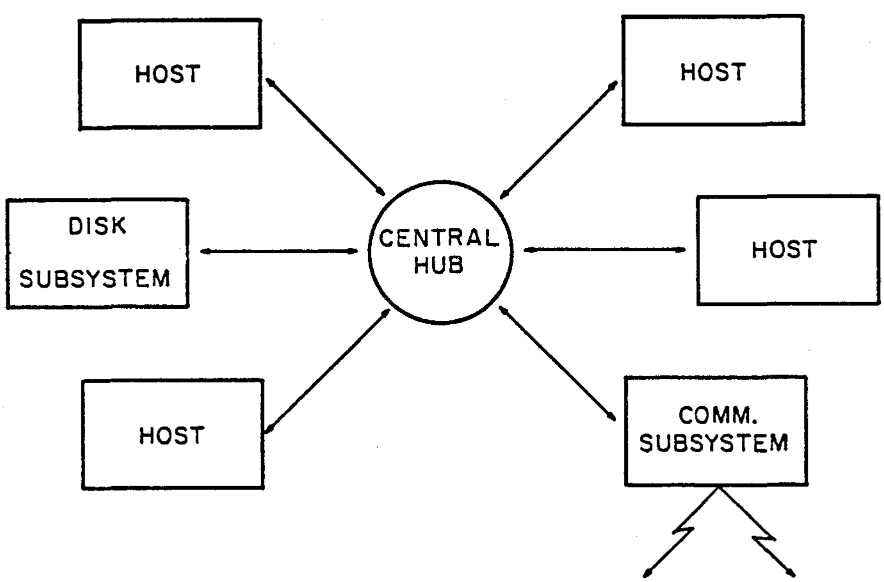


Figure 3-17. LDDI with central hub.

The OSI data link layer is not divided into sublayers for the LDDI. The data link layer has the detection of transmission errors as its principal function, using a 32-bit polynomial cyclical redundancy check (CRC) for a frame check sequence (FCS). Other functions include destination address filtering, source address insertion, end-of-message detection, and acknowledgment for correctly received nonbroadcast messages.

The physical layer has two LDDI sublayers, the physical protocol sublayer and the physical interface sublayer. The physical protocol sublayer provides as its functions an arbitrated and priority transmitting service to the data link layer. This arbitrated transmitting service provides fair or round-robin arbitration for stations wishing to send data on a path. It begins when the data link layer requests transmission via a specified path that is decided by the physical contents that are then sent through the physical interface sublayer on Path A or Path B (Figure 3-17). There also are two arbitration protocols in the LDDI physical protocol sublayer, one for passive interconnection media, and the other for active network hubs controlling the arbitration. Arbitration in the passive mode is similar to the CSMA/CA access method that is described in Section 2.3.3 for Broadcast Recognition with Alternating Priorities.

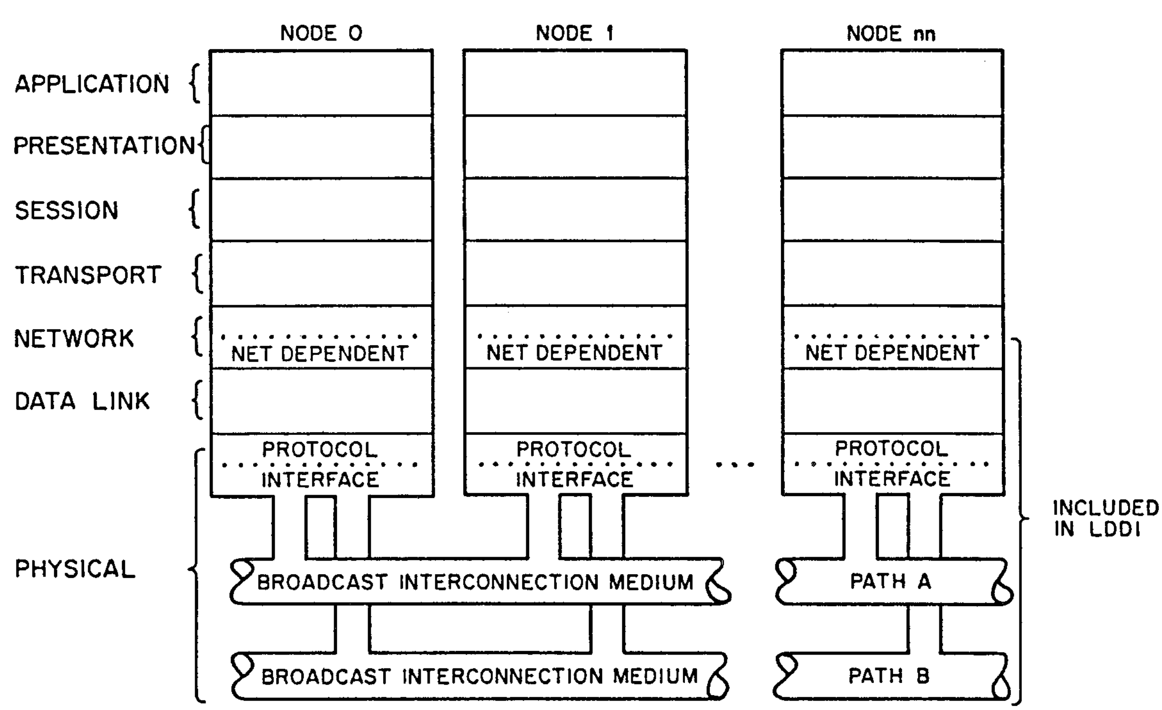


Figure 3-18. Dual bus and LDDI layering.

There are two physical interface sublayers specified in the current LDDI. One is for a single 50 Mb/s linear coaxial cable bus that uses broadband modulation. The second is for a 70 Mb/s dual cable (one transmit, one receive) using baseband modulation with Manchester coding. Each path of the dual cable is capable of 70 Mb/s. A summary of some of the physical interface characteristics of the two LDDI's is shown in Table 3-7. The broadband interfaces use the CATV spectrum of 35 MHz to 200 MHz (Burr, 1983).

The initial LDDI work using a linear bus and broadband interfaces is based on a Loosely Coupled Network (LCN), which is a commercially available 50 Mb/s local network available from Control Data Corporation (Burr, 1983). The star network using a central hub with baseband modulation was added to accommodate a VAXcluster structure with a Computer Interconnect (CI) from Digital Equipment Corporation. Another reason is that potential use of fiber-optic cable is suitable for the star topology and is not practical for a linear bus at this time. [A description of the CI is given in Strecker (1984).]

Table 3-7. Draft Proposed Standards for LDDI and FDDI (Summary)

CHARACTERISTIC	LDDI		FDDI
Topology	Linear bus	Star	Ring (star-wired)
Access Method	CSMA/CA	CSMA/CA	Token passing
Modulation	Broadband	Baseband	Baseband
Data Rate	50 Mb/s	70 Mb/s	100 Mb/s
Coding	Differential phase shift	Manchester ---	4 of 5
Cabling	Single	Dual	---
Medium	75-ohm CATV	50-ohm CATV	Optical fiber
Stations (max)	8 per 1 km, 28 per 500 m	16 per passive hub 228 per active hub	1000

3.2.2 Fiber Distributed Data Interface

The FDDI project of X3T9.5 intends to produce an American National Standard for protocols and hardware to be effective at 100 Mb/s using a token ring architecture. It will use fiber optics as a transmission medium to connect mainframe computers and peripherals over distances of several kilometers in circumference.

At present the data link and physical layers of the OSI reference model are each divided into two sublayers for the FDDI (Figure 3-19). (Note that this figure is not based on any official figure; it is based on an interpretation of the text in the standard.)

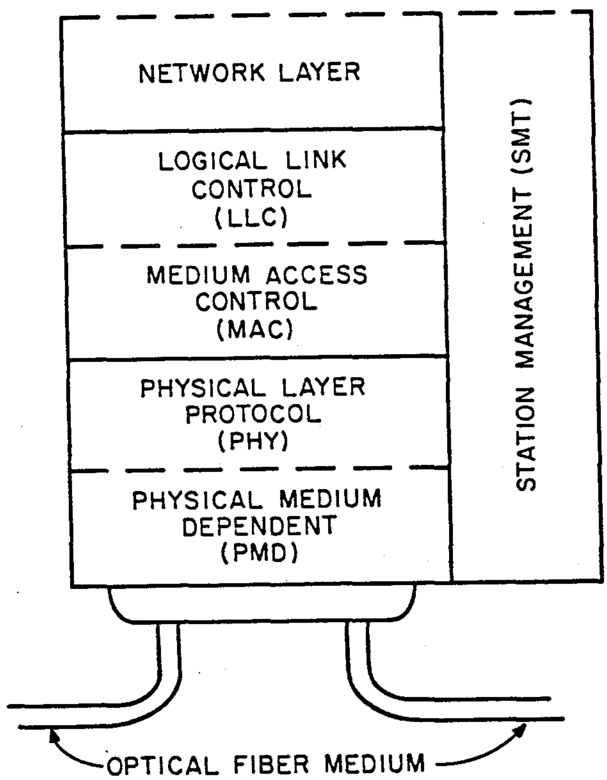


Figure 3-19. Layers for FDDI model.

The data link layer contains the LLC and MAC sublayers. It defines protocols to provide services to the network layer and the MAC that provides support to the LLC and higher layers. The functions of the MAC are to provide deterministic access to the medium, peer-to-peer address recognition, and generation and verification of frame check sequences. The MAC is based on the IEEE 802.5

token ring standard and has been modified to accommodate the higher speeds of the FDDI while retaining services and facilities (X3T9.5, 1984b). The philosophy of X3T9.5 has been to follow the 802.5 standard whenever practical. This simplifies bridges and gateways to lower performance rings and aids in understanding the FDDI. The frame formats and token protocol are derived from the 802.5 effort (Ross and Burr, 1984). For example, the most significant bit in a field is sent first.

The physical layer has the physical (PHY) and physical medium dependent (PMD) sublayers (X3T9.5, 1984c). The PHY establishes clock synchronization and encoding and decoding of the code-bit stream for use by higher layers. The PMD provides the digital baseband point-to-point communications in the FDDI network (Figure 3-20).

A station management (SMT) standard provides the station level control to manage the processes in the FDDI layers so that a station may work cooperatively on a ring. The SMT controls configuration management, fault isolation and recovery, and scheduling procedures.

A summary of FDDI characteristics is shown in Table 3-7. Optical fiber medium, and a 100 Mb/s data rate using baseband modulation are shown in comparison to the LDDI. A 4 of 5, or 4B/5B code, is used instead of the Manchester that is part of the 802.5 token ring. The 4 of 5 has an 80 percent efficiency while the Manchester code has 50 percent efficiency (Ross and Burr, 1984). Using the increased efficiency of the 4 of 5 allows using a 125 Mbauds/s signaling rate rather than 200 Mbauds/s signaling rate that would be required for a 100 Mb/s Manchester link [note clock and phase lock loop (PLL) in Figure 3-20]. This permits use of inexpensive LED's and PIN diode receivers that operate at 125 MHz (Joshi and Iyer, 1984).

The elasticity buffer (Figure 3-20) is used in each station to compensate for differences in frequencies. It allows for bits that must be dropped when the outgoing frequency is less than the incoming frequency.

The main differences between the FDDI and the 802.5 token ring are summarized by Ross and Burr (1984):

- optical fiber rather than electrical links
- a 100 Mb/s versus a 4 Mb/s data rate
- FDDI uses a fully distributed protocol with no master station

- improving the reliability of rings is explicitly defined in the FDDI standard (i.e., use of station bypass techniques, standby rings, star-wired ring topology)
- FDDI uses a timed token rotation priority scheme.

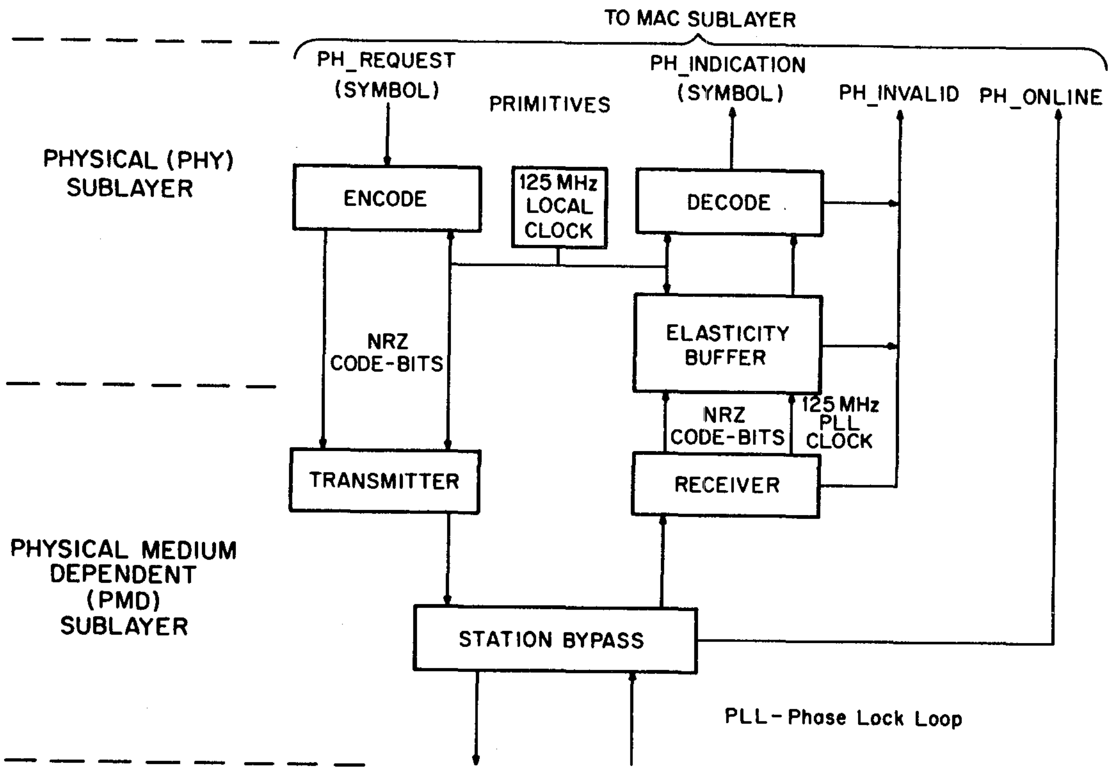


Figure 3-20. FDDI physical layer block diagram.

3.3 Military Standards 1553 and 1773

Two military standards in the local network category are MIL-STD-1553B and MIL-STD-1773. MIL-STD-1553 was developed by the Society of Automotive Engineers (SAE) subcommittee AE-9B and subsequently adopted by the Department of Defense primarily for use in military aircraft (Relis, 1983; Omnicom, 1984c). Intended for an extremely high noise environment, these military standards can be useful for industrial and commercial applications requiring reliable performance under adverse conditions.

MIL-STD-1773 is a proposed standard with a primary objective of being able to easily use fiber optic cable in 1553B avionics that use shielded twisted-pair wire. The main impact of 1773 would be on the bus drivers/ receivers and the transmission medium, although the 1553B bus topology could also be changed. Overall, MIL-STD-1773 closely follows MIL-STD-1553B paragraph by paragraph (Relis, 1983). The difference is in replacing wire terminology and electrical parameters with fiber-cable terms and optical parameters. There is little affect on protocols.

A poll and select access method to the medium is used. Bus communications are initiated by commands issued by a bus controller (i.e., a station) to a remote terminal. The controller and terminal contain protocol logic and transceivers that link the access control to the medium. A dual redundant bus is frequently used in implementing MIL-STD-1553B (Figure 3-21). An example of a MIL-STD-1773 dual redundant star topology is shown in Figure 3-22. Redundancy is needed because high reliability is paramount. With the failure of a primary system, the secondary systems are mandatory. In either the bus or star, the controller can be changed to a remote terminal via token passing.

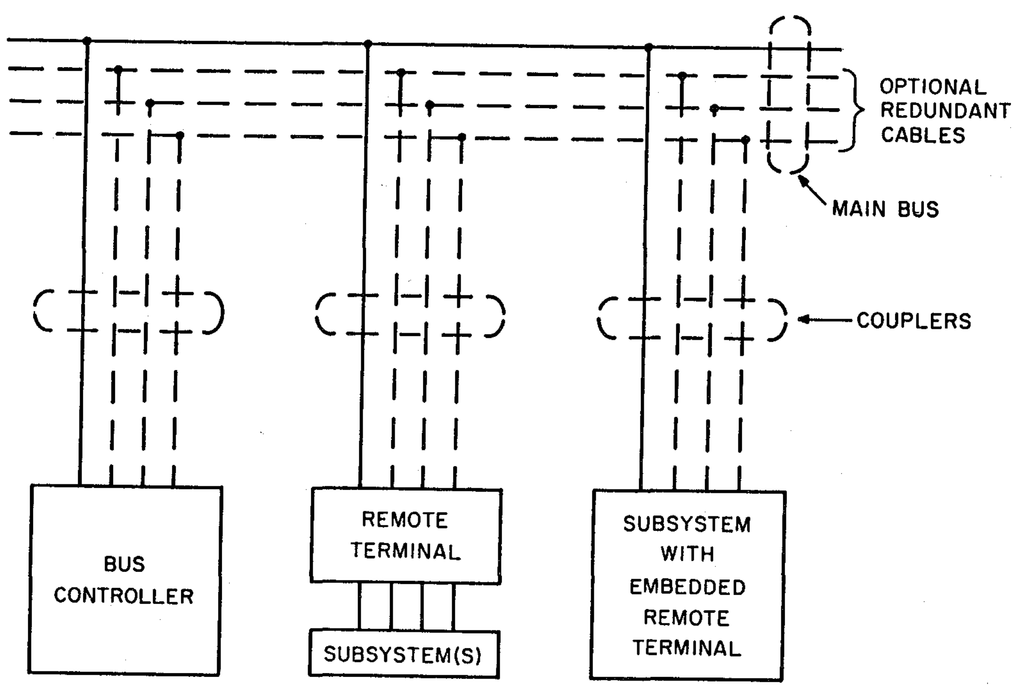


Figure 3-21. MIL-STD-1553B dual redundant bus topology.

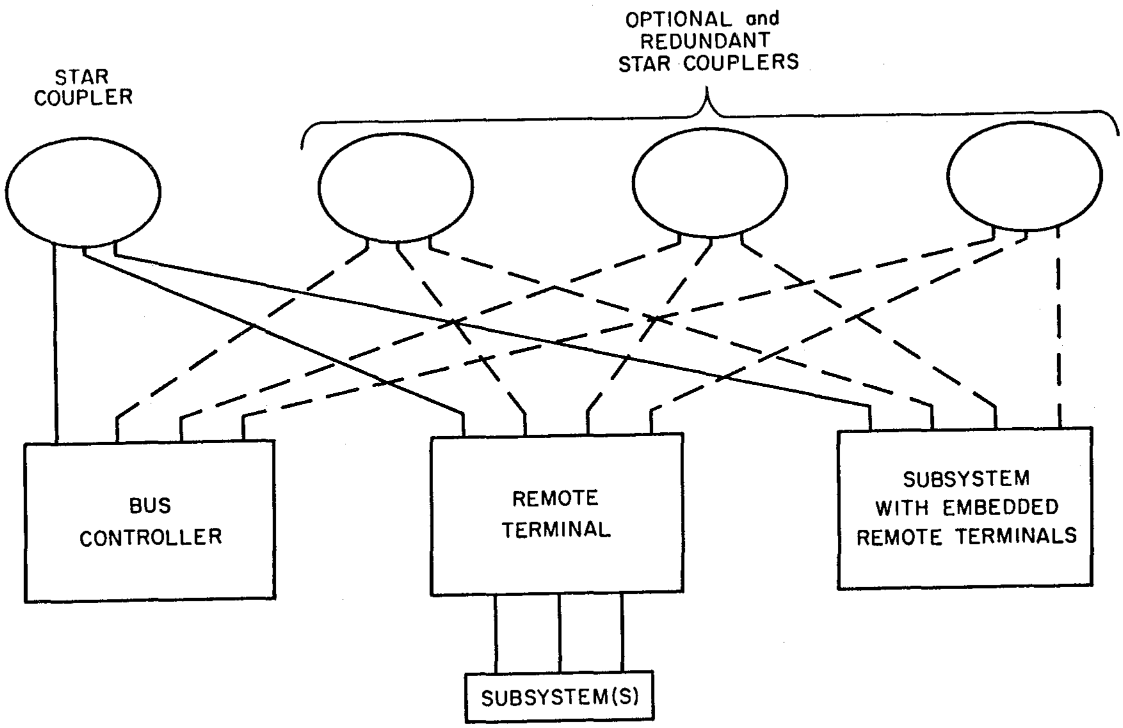


Figure 3-22. MIL-STD-1773 dual redundant star topology.

The physical layer for MIL-STD-1553B defines bus architecture, electrical signal, and several physical characteristics. A data bus interface scheme to the medium (twisted-pair wire) uses transformer coupling. A terminal transceiver is in a receive state when the coupling has high impedance and in a transmit state when the coupling has low impedance. Isolation resistors in the coupling permit bus operation to continue when a station short occurs, or when a transceiver is locked in a low impedance state. Isolation transformers protect against damage from high common mode voltage and eliminate terminal damage if a stub line (i.e., line drop) is shorted to ground.

The MIL-STD-1773 fiber-optic cable receiver requires an optical/electrical transducer and the transmitter requires an electrical/optical transducer. MIL-STD-1773 also allows unidirectional or bidirectional fiber. If unidirectional fiber cable is used, a separate transmit and a separate receive fiber are required for the data bus interface. Only one fiber is needed for transmit/receive when bidirectional fiber is used.

Bilevel Manchester coding is used in 1553B and 1773. It permits the use of transformer coupling and signal-derived clocking at the receiver.

A summary of characteristics is shown in Table 3-8.

Table 3-8. MIL-STD-1553B Characteristics

Access Method	Polling
Topology	Bus
Modulation	Baseband
Coding	Manchester II
Data Rate	1 Mb/s
Medium	Shielded twisted-pair wire
Bus Length	150 m
Stations	1 controller/31 remote terminals

Note: MIL-STD-1773 (Proposed) has similar characteristics except medium is fiber optic cable and alternate configurations are acceptable: including a bidirectional T-coupled bus, a bidirectional hybrid coupled bus, a reflective star coupler, and a transmissive star coupler.

4. INTERNETWORKING

The objectives of networking are based on a desire to connect terminals, computers, and other local network devices to one another. The devices may be located on 1) the same LAN, 2) LAN and a Wide Area Network (WAN), or 3) geographically separate LAN's where a WAN is used to connect the LAN's. For abstract systems, a local network device is an end system where the device appearance conforms to the seven-layer OSI reference model. One end system is connected to another through an intermediate system (Figure 4-1). In this figure, a real end system is connected through a real subnetwork (e.g., LAN) to another real end system. In some configurations, more than one subnetwork/intermediate system may be necessary to connect real end systems. Within the ISO (1984) a set of two-tiered figures has been used to depict an architectural organization of the network layer of the OSI reference model. This two-tier convention is used in Figure 4-1 and other figures in this section to map the functional organization of the OSI reference model to the "real world" of LAN's and WAN's.

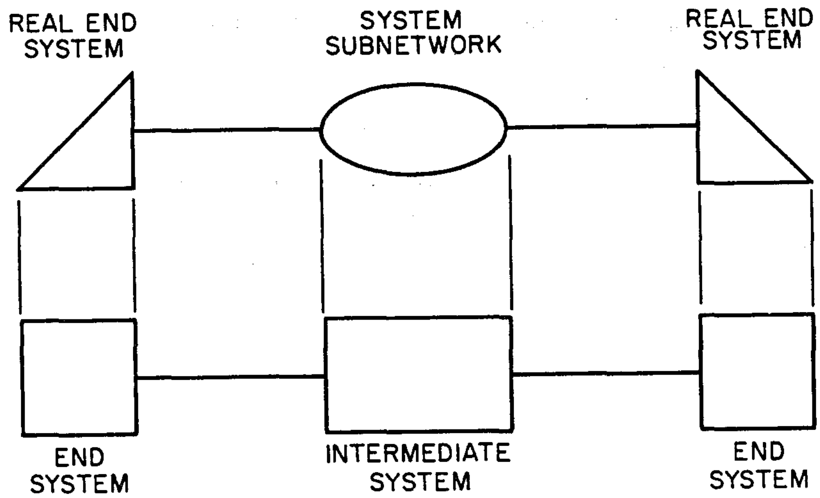


Figure 4-1. End systems connecting through an intermediate system.

Various types of networking are considered in the draft IEEE Standard 802.1 (1983d). These are based on a need for intra- and internetwork connections.

Intranetwork connection is concerned with combining of components or segments of LAN's. This is the prime concern within the 802.3 (CSMA/CD), 802.4 (token bus), and 802.5 (token ring) standards. Intranetworking is outside the scope of detailed development within 802.1.

Internetwork connection is concerned with combining LAN's and WAN's. Examples of WAN's are the Defense Data Network (DDN) or an X.25-based packet-switched public data network (PSPDN). Internetworking is within the scope of detailed development within 802.1.

Figure 4-2 depicts the functional organization of the layers of a LAN relative to the "real world" of an 802 LAN. An interworking unit (IWU) is shown within the 802 LAN real subnetwork. An IWU may be represented as an integral part of a real subnetwork as it is here (e.g., a baseband or single channel broadband repeater). An IWU may also be represented as a separate intermediate system called a relay system (ISO, 1984). Examples of this are bridges and gateways.

Bridges and gateways are used to link LAN's while repeaters are used to extend the cable length of baseband or single channel broadband LAN's. Bridges take care of intranetwork protocols while gateways are needed for internetwork protocols. Repeaters amplify and retransmit all signals including collisions on a network (e.g., IWU within an LAN, Figure 4-2).

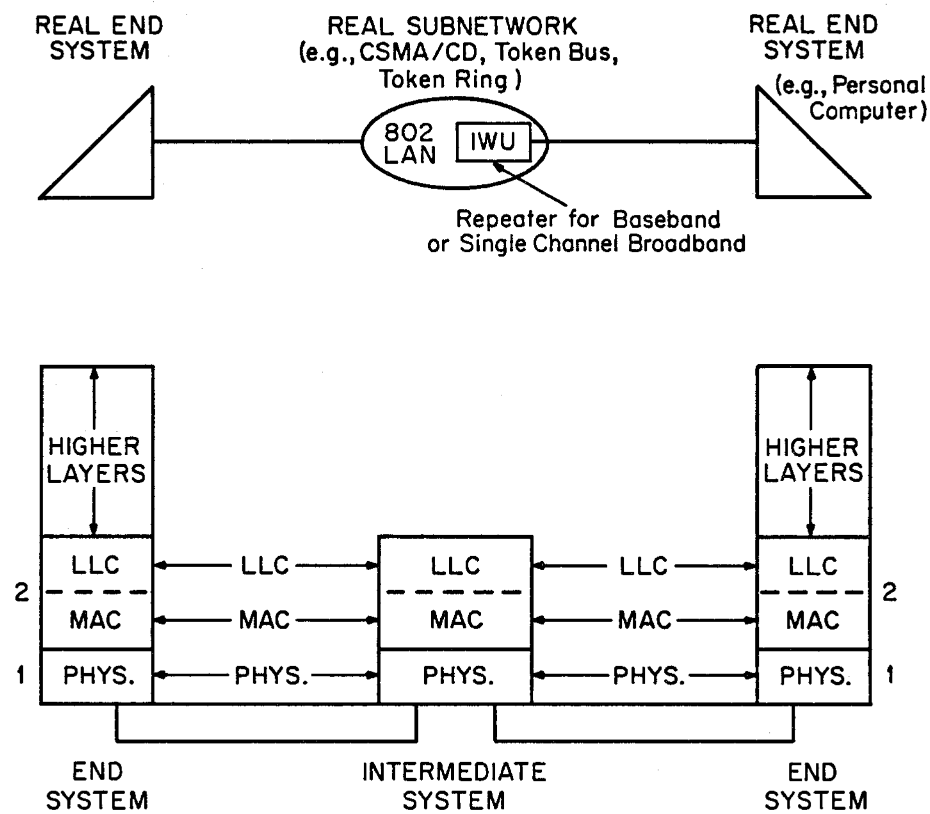


Figure 4-2. Real and abstract representations of an 802 LAN.

4.1 Bridge Connections

A bridge provides a transparent connection for geographically separate but homogeneous local networks (Stallings, 1983). Bridges create the appearance of a single composite network when network protocols, such as addressing, are similar. A bridge must be capable of performing the following functions for two similar networks, A and B, to communicate.

1) Read all packets transmitted on network A, and accept those addressed to B.

2) Retransmit the packets to network B by using the MAC for B. (Recall that the MAC provides addressing functions.)

3) Handle B-A traffic the same way.

A bridge is also useful when all the end systems (terminal devices) are in one location. Reliability is provided by partioning a network into units so that one network failure does not disable all communications.

Performance is maintained in a smaller network by splitting the available traffic. Performance usually declines as the length of the medium is increased or more stations are added.

Security is increased on an isolated smaller network by being able to limit dissemination of sensitive information to a restricted network. For example, encrypted messages could be carried on network A and not permitted on network B.

Networks in separate buildings can be connected by microwave or infrared bridges across highways or bodies of water. Convenience and economy are served by using a bridge rather than attempting to bury cable at a high cost.

An example of connecting equivalent 802 LAN's is shown in Figure 4-3. The connection is made by a bridge or two half-bridges located at each LAN that only encompass the physical and MAC layers. Only the MAC frame station address needs to be recognized by the bridge for transmission from LAN A to LAN B. Otherwise the messages remain on one network or the other. Neither content nor format changes are made to the frames as they pass between network A and B, although additional frame encapsulation is performed before transmission between half-bridges.

4.2 Gateway Connections

Internetworking is used to describe a communication service between stations on dissimilar LAN's or between LAN's and other networks such as WAN's. Gateways are used to adjust for the different protocols on the dissimilar (heterogeneous) networks (Stallings, 1983). The differences between the different LAN's, and LAN's and WAN's can be extensive in the following areas.

1) Addressing. A form of global network addressing and directory service is needed to account for differences in end-point names and addresses.

2) Packet size. Fragmentation may have to be used to break up large packets into smaller units.

3) Interfaces. Different interfaces exist for the 802 LAN's and the WAN's such as on the Defense Data Network (DDN) with an X.25 interface.

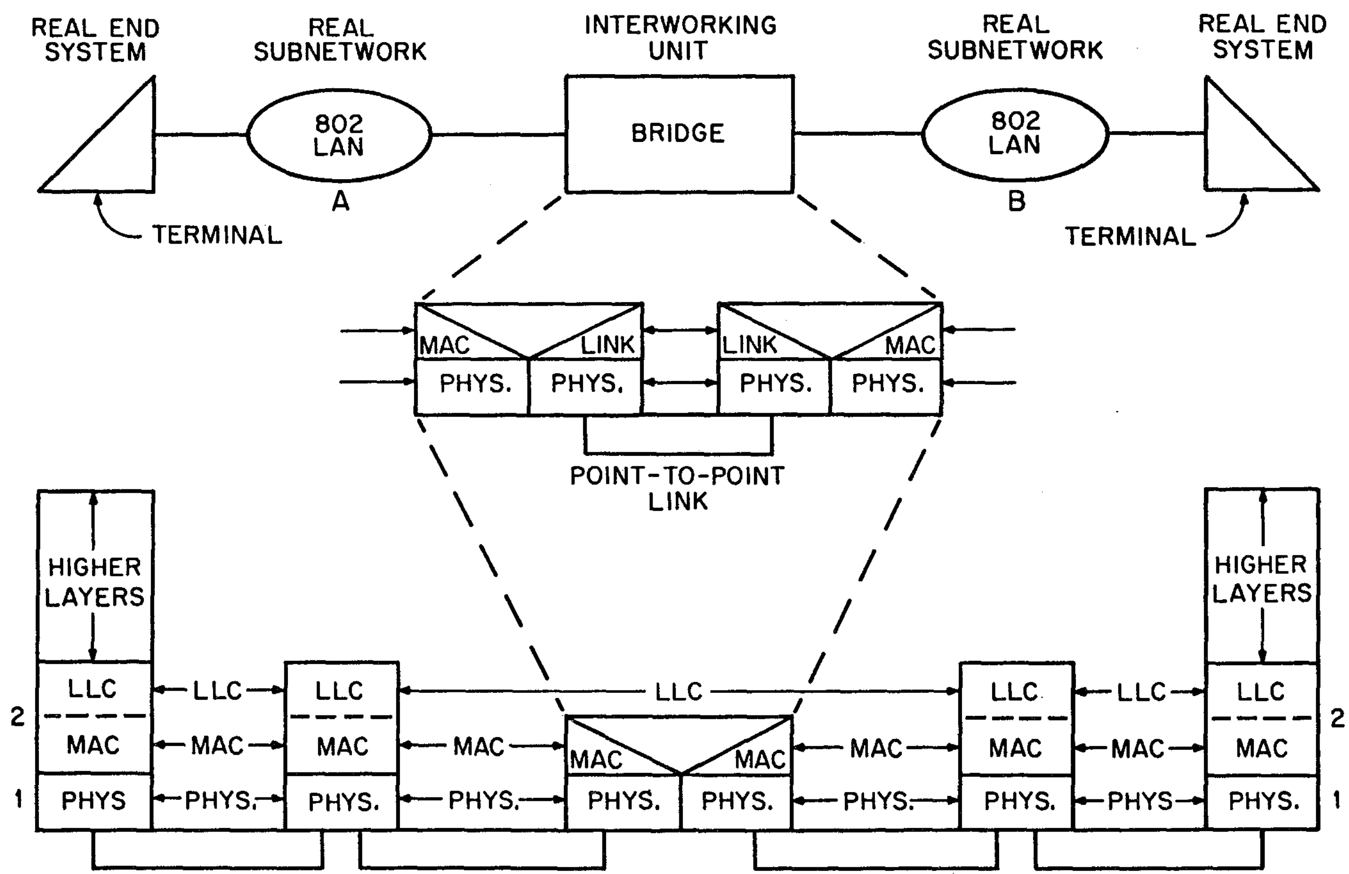


Figure 4-3. LAN's connected via a bridge.

4) Time-outs. Different timing periods are required for connection-oriented service across multiple networks. An X.25 network that awaits an acknowledgment will retransmit unnecessarily if a time-out period expires.

5) Error recovery. Each subnetwork may be reliable, or not, and recovery procedures may be nil or extensive. Error recovery procedures in an internetwork system should not depend on a subnetwork.

6) Status reporting. Status reporting is handled differently in subnetworks, although information concerning internetwork conditions is necessary.

7) Routing techniques. Differences in flow control and fault detection of subnetworks have to be accommodated between stations.

8) Access control. Various subnetwork access control techniques will have to be invoked.

9) Connection-oriented or connectionless. The relay services considered in 802.1 (IEEE, 1983b) may be connectionless or connection-oriented. The internetwork service should be independent of a subnetwork's connection service.

Examples of internetwork connections are given in Figures 4-4 and 4-5. An X.25 packet layer protocol (PLP) is used in providing the OSI network-layer service in the LAN (not yet defined by IEEE 802) and simplifies the gateway to an X.25 network (Burg et al., 1984). The X.25 PLP can be used independently of the lower X.25 layers because of the modularity inherent in an OSI environment. Use of this approach allows stations on each 802 LAN subnetwork to communicate with each other. It is considered less complicated than using the Internet Protocol. However, it is still under consideration by the IEEE and ISO.

A Department of Defense (DoD) internetwork connection is represented in Figure 4-5. The geographically remote 802 LAN's are connected through gateways and the Defense Data Network (DDN). In this scenario, MIL-STD-1777, the Internet Protocol (IP) is designated as part of the OSI environment at the end user's system, the gateway, and the DDN at the network layer. (Note that some believe the IP should be placed between the network and transport layers of the OSI reference model.) By itself the IP provides a connectionless (datagram) service for routing and delivery of messages. A reliable connection-oriented service is provided the IP when coupled with DoD MIL-STD-1778 Transmission Control Protocol (TCP).

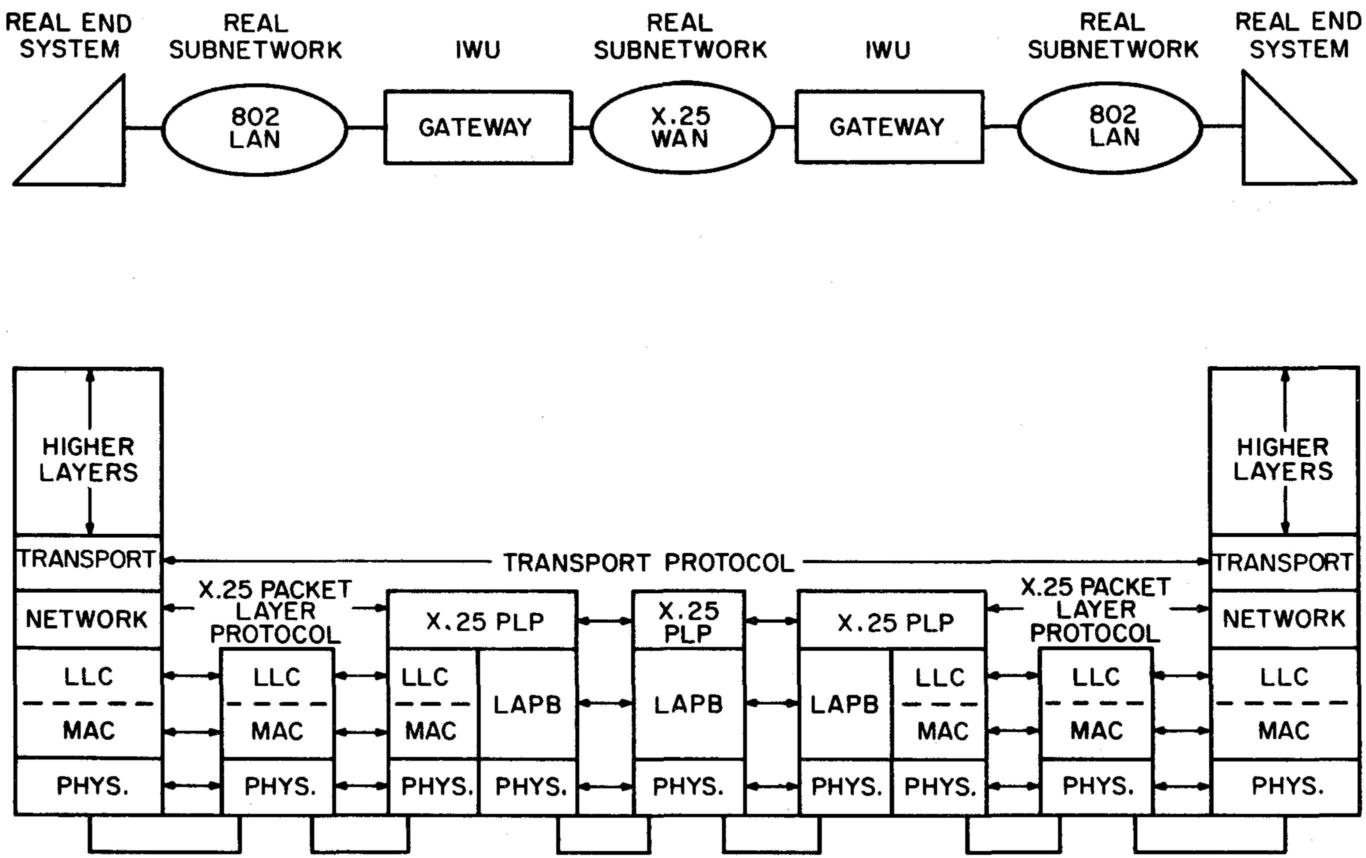
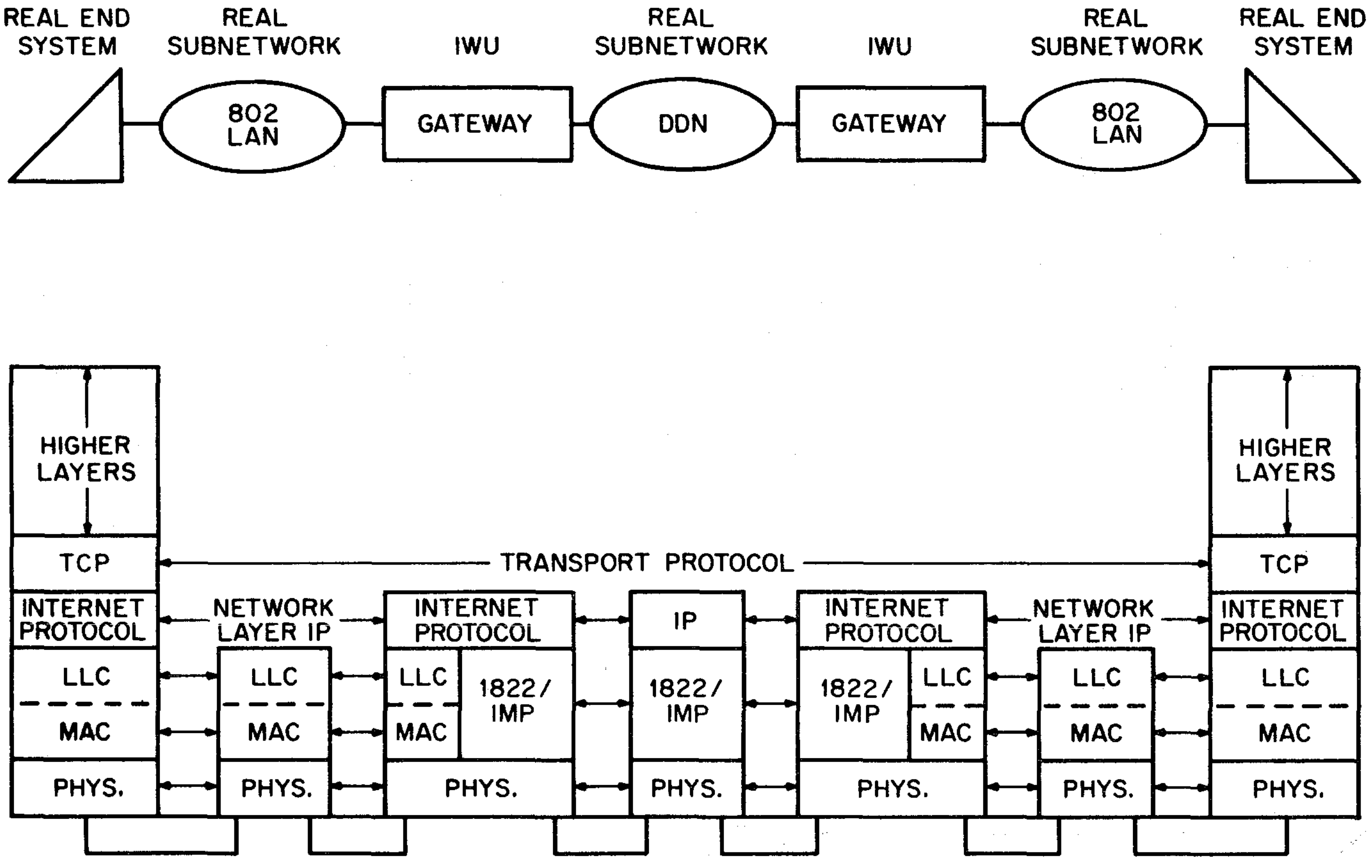


Figure 4-4. Connection of LAN's via an X.25 WAN and gateways.



NOTE: IMP – Interface Message Processor

Figure 4-5. Connection of LAN's via the DDN and gateways.

5. LAN/PBX

Convergence of technologies between LAN's and PBX's is of major importance to the user, although the desirable extent of integration could be viewed at two extremes. One view can be that a distinct separation of data systems is appropriate. A second view can be that the total integration of voice and data is not only appropriate, but necessary. Considering the first view, the assumption is that PBX's are oriented to voice applications while LAN's are exclusively for nonvoice purposes such as alphanumeric data transfer and computer resource sharing. Capitalizing on the strengths of PBX and LAN systems results in optimizing performance for voice or data information transfer. However, late model PBX's such as third-and fourth-generation switches, with nonblocking or virtually nonblocking architectures, have integrated voice and data capability. At the same time, voice communication capability is being developed for LAN's, although with some difficulty, because of the nature of voice traffic. Use of a single broadband channel for exclusive voice application is a viable approach.

The use of PBX's for voice applications is mature and well established but these same features serve as drawbacks for bursty data traffic (Tsao, 1984):

- PBX switch capacity is inefficiently used; most data sessions are bursty (i.e., short data and long idle periods).
- Each port supports a "low" fixed-bit rate (i.e., 64 kb/s); this requires that "high" bit-rate devices have service through multiple dedicated ports.
- Circuit switching is not data-feature intensive, since host multiplexing of several channels through a common host port is not easily provided in a point-to-point switching environment.

An LAN high speed channel overcomes these drawbacks by:

- providing a high network capacity
- satisfying requirements of high speed devices
- allowing efficient bandwidth sharing among devices by allowing bursty operation
- permitting easy host channel multiplexing through common channel-sharing by forming packets that contain source and destination addresses.

Desirable PBX features include:

- central management for system configuration and performance data gathering
- network maintenance for fault detection and isolation
- security, due to the use of a star topology.

The different types of traffic that are handled by PBX's and LAN's dominate the problem of interfacing the two technologies. Voice traffic on PBX's consists of digitized bit streams (32 to 64 kb/s) that last an average of 100 seconds. It is desirable that voice be delivered in real, or near real, time. Compressed video has a constant data rate of several Mb/s for lengthy periods. Traffic on LAN's is generated by terminals, host computers, intelligent workstations, and graphics terminals. The transmission rate can vary from 300 b/s to several Mb/s, may be asynchronous or synchronous, and is characterized as bursty with long periods possible between data transmissions. Delays of several hundred seconds is acceptable for LAN traffic. The trend of convergence between LAN and PBX capability results in more efficient use of communication resources while maintaining an equilibrium in capital investment and overcoming different traffic characteristics.

Each generation of PBX's may be characterized, although not limited, to the features shown in Table 5-1.

Table 5-1 PBX Generation Characteristics

Generation	Control	Switching	Loops
First	Mechanical	Analog	Analog
Second	SPC(1)	Analog	Analog
Third	SPC	Digital	Digital/Analog
Fourth (2)	Distributed	Distributed	Digital

Note: 1) SPC = Stored Program Control

2) Interfaces to voice communications and data LAN's are included.

Fourth-generation switches in this evolution should provide the following features (Simmons, 1984):

- Reliable, distributed control
- Location independent switching
- Modular hardware and software
- Non-blocking switch capacity

- User terminal and computer mainframe capability
  - standard and dedicated terminals
  - accommodation of bit rate and protocol requirements
- PBX/LAN interface integration
- WAN interfaces
- Fully secure system architecture
- Acceptable cost justification
- Comprehensive support by the vendor.

Part of the philosophy of the fourth-generation switches is user acceptance of, and requirements for, these criteria. Since many PBX's do not include all these features, a lack of user acceptance may prevail for some units.

Another factor for consideration of fourth-generation switches depends on the extent of implementing the concept of Integrated Services Digital Networks (ISDN) and the use of CCITT Signaling System No. 7 for communications control (ITS Staff, 1983).

While the "separate network" philosophy may have been valid at one time, the PBX and LAN technology should be integrated so that the resulting system optimizes service (e.g., voice, data), performance (e.g., error rate, reliability), connectivity, and cost. A gateway between the PBX and the LAN has been suggested as the key to integration (Houldsworth, 1983). A single network is achieved by connecting separate PBX and LAN entities along with their respective user stations (Figure 5-1). The development of gateways for systems already in place is a logical approach.

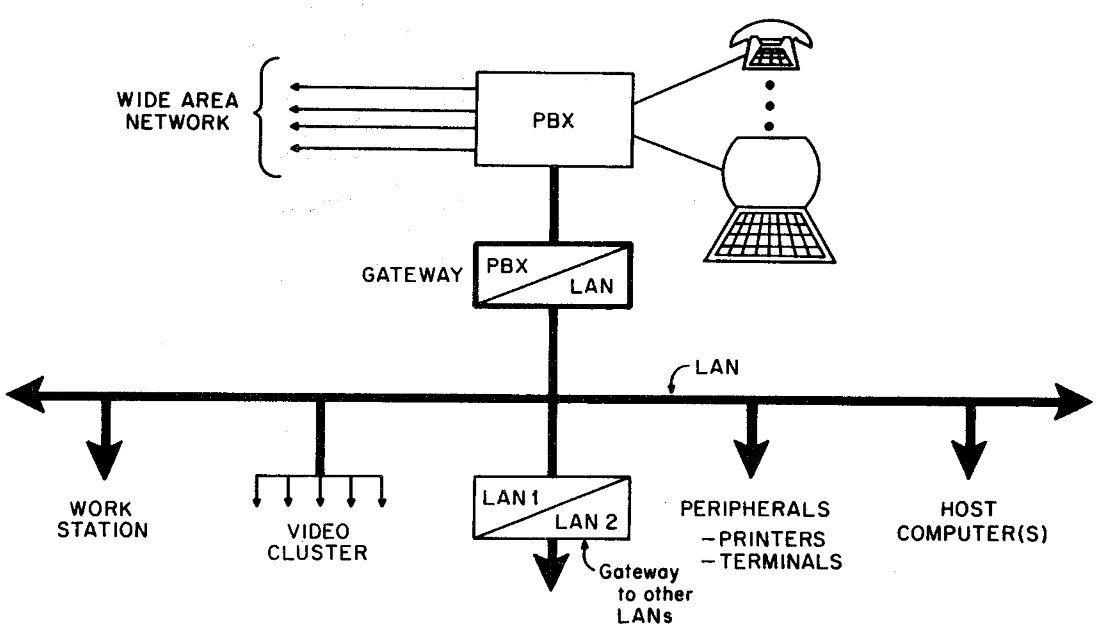


Figure 5-1. LAN/PBX convergence through a gateway.

5.1 Protocol Conversion

A protocol conversion that uses the PBX as a core communications unit and interfaces with an LAN is proposed in a paper by Maebara and Takeuchi (1984). A methodology for conversion is developed that is based on the first three layers of the OSI reference model and five phases for a communication protocol according to call progress. The five phases are:

Phase 1: call path connection

Phase 2: link establishment

Phase 3: information transfer

Phase 4: link termination

Phase 5: call path clearance.

A matrix combines the five phases and three layers to identify the intercommunication problems (Figure 5-2).

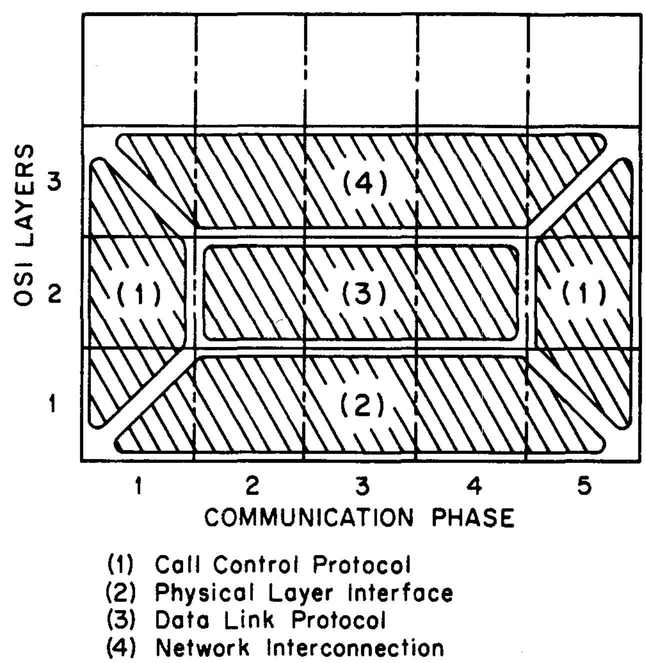


Figure 5-2. Intercommunication problems for protocol conversion.

The four identified problems are:

1) Call control protocol (signaling) variety: various call control protocols including telephone call signaling must be handled by the PBX. These involve start-stop (CCITT X.20) and synchronous (CCITT X.21) procedures.
2) Physical layer interface variety: compatibility problems occur when different physical layer interfaces are used (i.e., CCITT X.20, X.21, or X.21 bis, which is equivalent to RS-232-C or RS-449). A determination is required as to which interface control signals are transported through the PBX and subscriber lines. Speed conversion is also needed.
3) Data link protocol variety: various data link protocols need to be converted. Protocols include free wheeling, Basic Mode Control Procedure, and High Level Data Link Control (HDLC).
4) Network interconnection: connections are needed among the PBX, an LAN, and a WAN. Translation of numbering/addressing schemes for the networks by the PBX is necessary.

   Other problems: The PBX, a) maintains individual terminal characteristics information, b) determines the need for protocol conversion, and c) selects conversion functions as necessary.

These problems (1-4) need to be examined for LAN/PBX interfacing through a gateway (Figure 5-3). Also, consideration of connectionless and connection-oriented procedures is needed--for example, by using a transport control protocol in conjunction with an internet protocol.

Examination of the problems according to Figure 5-2 shows the following:

1) PBX terminals can be connected to the gateway when the call control protocols are standardized by the line interfaces.
2) The medium access method differs for the PBX and LAN, and an interface control signal is not needed in the LAN. The gateway terminates the signal from the PBX.
3) The standardized call control protocol codes can be selected by the gateway conversion functions.
4) Since the PBX and LAN have different numbering and addressing approaches, the gateway translates the methods by using a special number and second selection signal process. This does not restrict the numbering scheme/addressing approaches.

Based on this rationale, the software structure for protocol conversion for PBX/LAN interconnection is shown in Figure 5-4. Note the MAC and LLC processes on the LAN side, and equivalent link layer conversions on the PBX side.

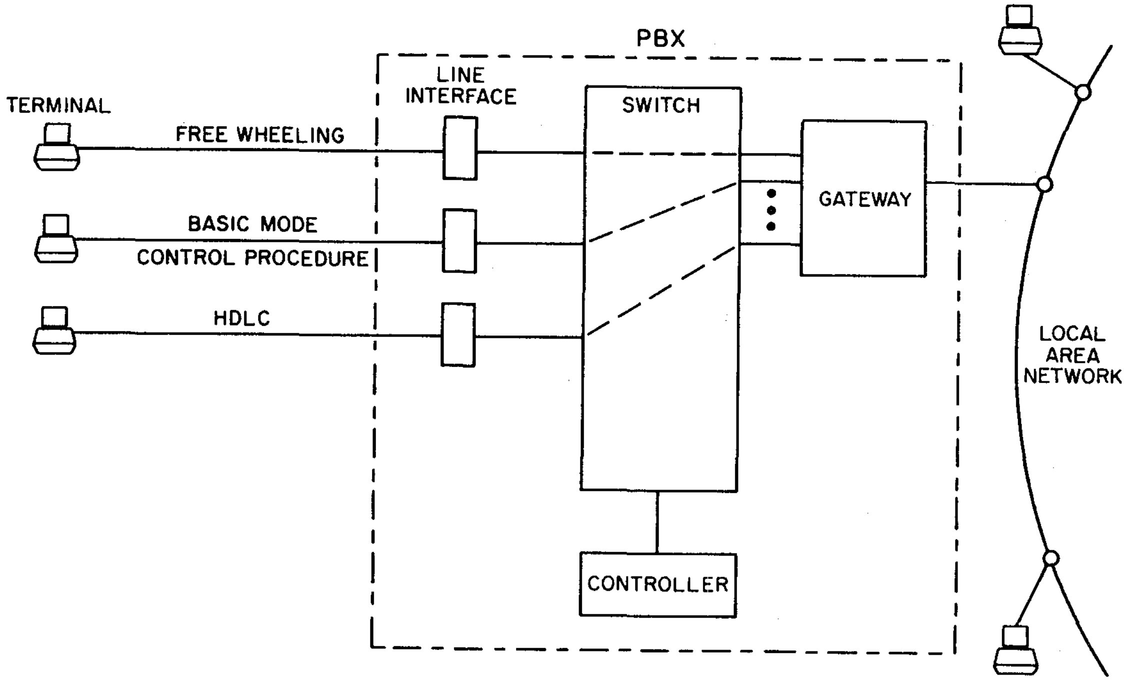


Figure 5-3. LAN/PBX interconnection with protocol conversion at gateway.

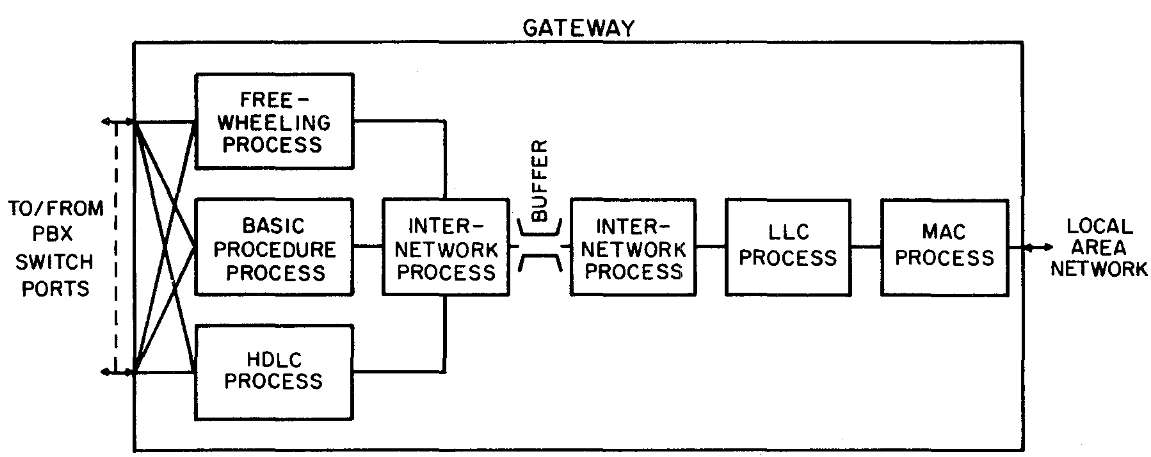


Figure 5-4. Software structure for the PBX/LAN gateway.

An experimental system based on these conversion considerations has been developed using a CSMA/CD type LAN with success. The reported speed conversion (i.e., 50 b/s to 56 kb/s) appears to be a limitation of the PBX transmission rate capability.

5.2 Integrated Architecture

The AT&T Information Systems Network (ISN), the Rose from CXC Corporation, and Ztel Private Network Exchange (PNX) are systems that attempt to combine the best features of PBX's and LAN's. Each combined LAN/PBX will be discussed in order.

The ISN provides for priority access using a star topology with a centrally located short bus at the hub (Figure 5-5). Real-time voice is not supported at this time although the architecture is capable of handling it (EEM, 1984b). A star topology, centralized control, multistation card modules, and twisted-wire pairs are based on PBX technology. Contention-based access and dynamically assigned bandwidth capability are borrowed from LAN technology. According to Acampora and Hluchyj (1984), this approach combines the advantages of the digital PBX, distributed bus, and ring architectures while avoiding their disadvantages. The access scheme works with an extremely short propagation delay on the bus, and α is minimized (see Section 2.5), although the packet length is only 180 bits. The bus and ring architectures have greater propagation delay compared to that of the short bus where the end-to-end delay is less than one bit. A drawback of the circuit-switched PBX is avoided by providing shared, packet-switched access to the high-speed short bus. This results in what is called "perfect scheduling" of packet transmissions where neither collisions nor idle periods exist if there are packets awaiting transmission.

The ISN is based on the AT&T Technologies DATAKIT virtual circuit switch (VCS). The DATAKIT VCS is a packet switch designed to operate in a hierarchal star topology network. In this configuration, a dual short bus architecture is used, with one bus for contention resolution, and the other for data distribution to network stations (Datapro, 1984a). For the ISN, three busses, the contention, transmit, and broadcast, are used in the backplane of the node (Figure 5-6).

The right to send is based on a permanent, or dynamic, assignment of priorities to a bus interface unit (BIU). Access is given to the BIU with the highest priority. Time on the busses is divided into fixed-length time slots. Transmit and contention busses use the same slot timing (generated by the

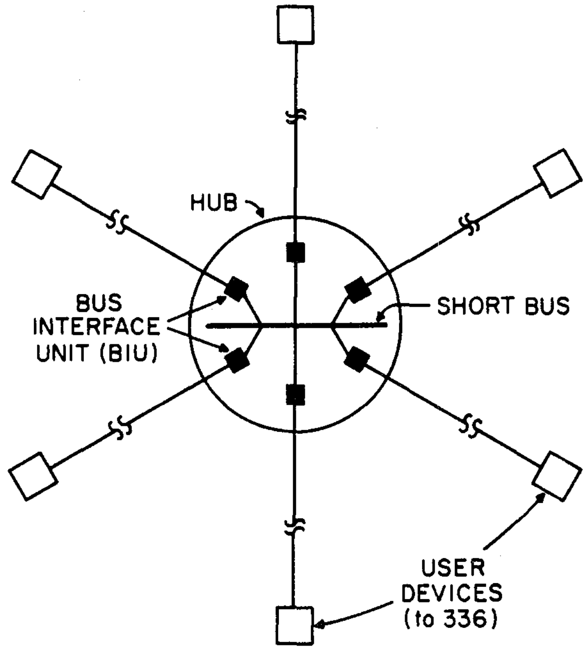


Figure 5-5. Star topology with short bus.

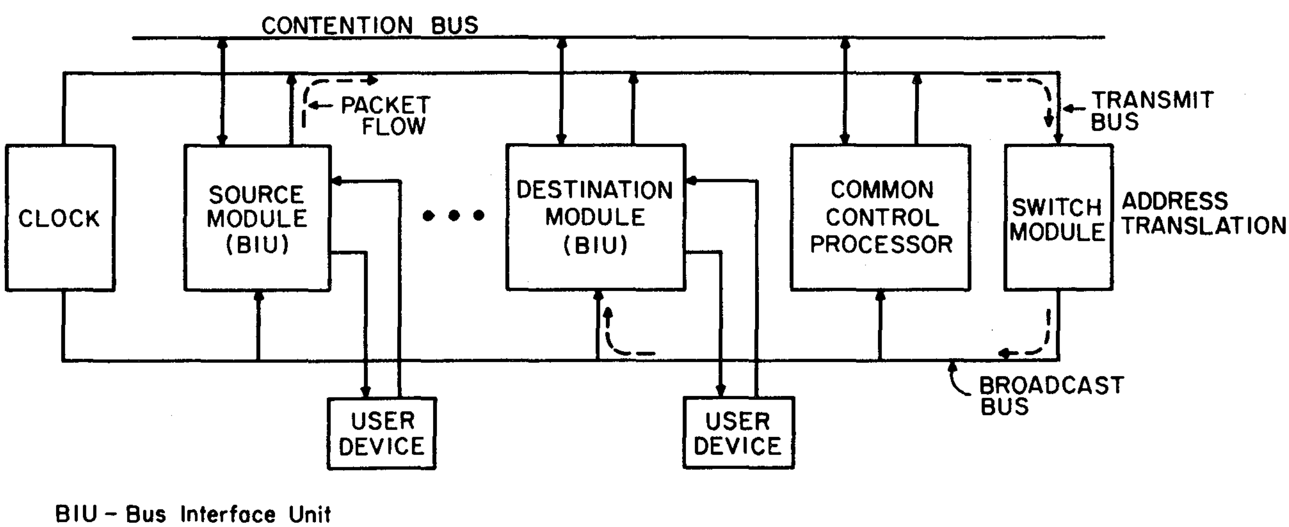


Figure 5-6. ISN node architecture.

clock module) and operate in parallel; contention for a given time slot on a transmit bus occurs in the previous time slot of the contention bus. A BIU ready to transmit writes its assigned priority on the contention bus, one bit at a time. The bus functions as a wired-OR gate with input from all active BIU's. A BIU can determine if any other BIU is attempting access to the same time slot by sensing the contention bus on a bit-by-bit basis. Transmission ceases if such a condition is detected. Access is granted in a particular time slot to the BIU with the highest priority. Collisions do not occur because the packet transmission time is concluded before contention is resolved for the next packet using this short bus architecture. Losing stations are assigned a "round-robin" flag that assures priority over stations that have already transmitted. "Fair" scheduling is achieved within a traffic type by assigning:

- high priorities for short interactive and real-time traffic
- low priorities for long file transfer.

In Figure 5-6, a module number uniquely identifies the BIU's. A channel number distinguishes different data paths within the module. The switch module translates packets containing source BIU and channel numbers to destination BIU and channel numbers. This transition from the transmit to the broadcast bus is established through a prior call set-up procedure, thus implementing a virtual circuit transport mechanism.

Currently, the clock rate is 8.64 Mb/s, which would make it incompatible with a 10 Mb/s Ethernet LAN. A change in the bus rate to 10 Mb/s is said to be possible (EEM, 1984b). The 4-pair twisted wire (quad cable) for user devices is the same as that prescribed for AT&T System 75 and System 85 PBX's. Up to 336 local user-devices can be supported by this switch controller. Optical fiber connection to four remote concentrators increases the support to 1,680 user devices.

The Rose communications switch from the CXC Corporation supports integrated voice and data communications. As part of a system cluster it provides for distributed switching, variable bandwidth assignment, and X.25 packet switching from a proprietary terminal. As part of a cluster, each switch is connected by two LAN's, a broadband ring, and an Ethernet baseband bus. Up to 25,000 ports can be supported by a cluster (Figure 5-7). The broadband ring operates at 50 Mb/s. This is divided to 33 Mb/s for circuit-switched voice and data operation, and in excess of 16 Mb/s for the future implementation of

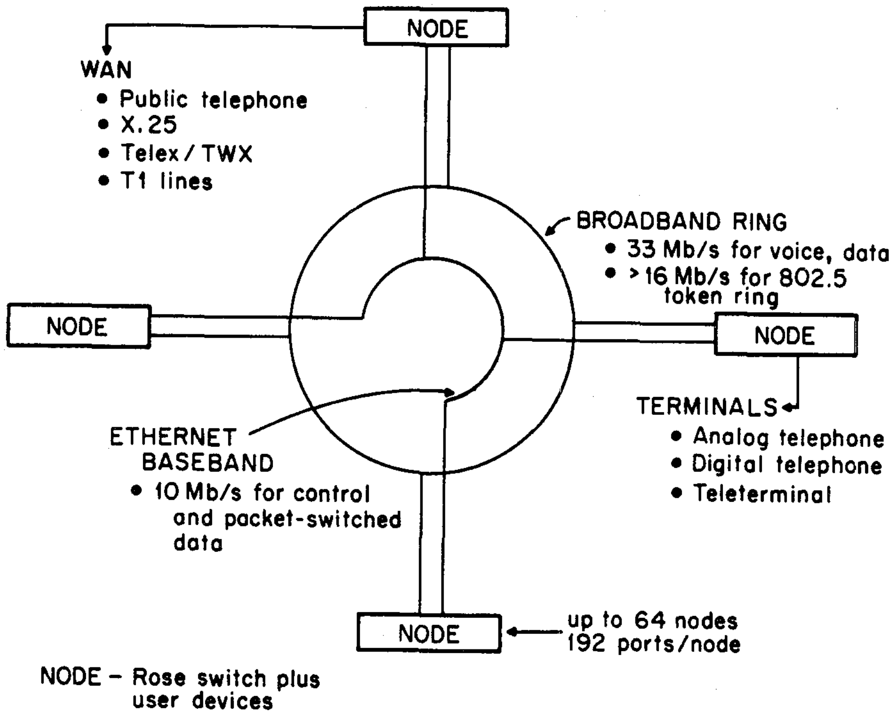


Figure 5-7. System cluster using distributed switching and processing.

the IEEE 802.5 token ring. The 16 Mb/s would be subdivided to four 4 Mb/s channels according to the standard. The Ethernet LAN, at 10 Mb/s, is used for signaling between nodes and for packet-switched data (Western Union, 1983). Plans are to eliminate the Ethernet in the future and use the token ring for signaling and packet data (Datapro, 1984b).

Individual communication processing nodes in each system cluster can serve as gateways to other networks, including central office analog telephone connections, X.25 packet networks, digital communication lines, and Telex/TWX facilities. Standard analog telephones, digital telephones, and proprietary personal teleterminals are supported by the switch. Each teleterminal has data capability for 19.2 kb/s asynchronous and 128 kb/s synchronous operation. Personal computers, printers, and minicomputers can be connected through the teleterminal to the processing node for network communications. Voice messages are digitized, stored on disc, and sent in the same way as alphanumeric data messages.

The Rose (called Vega by Western Union) has a distributed Per-Line-Switch architecture that defines a time-division-multiplex (TDM) slot of 8 kb/s. These 8 kb/s slots can be combined to produce between 8 kb/s and 512 kb/s circuit switched pathways to the teleterminals.

The broadband system uses rf modems and standard CATV technology. Software is based on the structure of the OSI reference model.

The Private Network Exchange (PNX) from Ztel, Incorporated, is an LAN/PBX based system, uses-fourth generation switch architecture, to support voice, data, and video. Some characteristics are similar to the CXC Rose switch, in the sense that both distributed control systems have separate LAN's that are used for different purposes. The PNX allows for connectivity to a public X.25 network through a gateway, interfacing to public voice telephone networks, T1 lines at 1.544 Mb/s, and emulation for connection to an IBM 3278 system (Zanini and Patrick, 1985).

There are three kinds of LAN rings used in a PNX. One is for packetized data and control signals, a second is for nonpacketized voice and data, and a third, when appropriately configured, is a backup for the first two (Datapro, 1984c). Each LAN ring operates at 10 Mb/s.

An IEEE 802.5 token ring handles signaling information between PNX switching units (Figure 5-8). This signaling information controls traffic on the voice LAN ring. Most data can be packetized and routed on the 802.5 LAN, but some is sent at rates of up to 56 kb/s in nonpacket form on the voice LAN. The voice LAN is a proprietary token ring that handles PCM-encoded voice information at up to 64 kb/s. Typically, multiple voice LAN's can be added incrementally, and one data LAN can handle alphanumeric information.

The PNX permits resource sharing of personal computers, minicomputers, facsimiles, compressed video, standard telephones, and proprietary telsets that handle voice and data. Each switching node can handle up to 512 ports per switching node for interfacing terminals or transmission facilities. A PNX network can be configured to support between 150 and 30,000 lines.

6. SUMMARY AND CONCLUSION

Local networks are generally defined as being communications networks that encompass a small geographic area. They provide resource sharing for devices or processes and, typically, are privately owned. Three types of local networks are discussed in this report: the LAN, the HSLN, and LAN/PBX. Technology components such as topology, transmission media, media access methods, and applicable protocols are described as part of the local network structure.

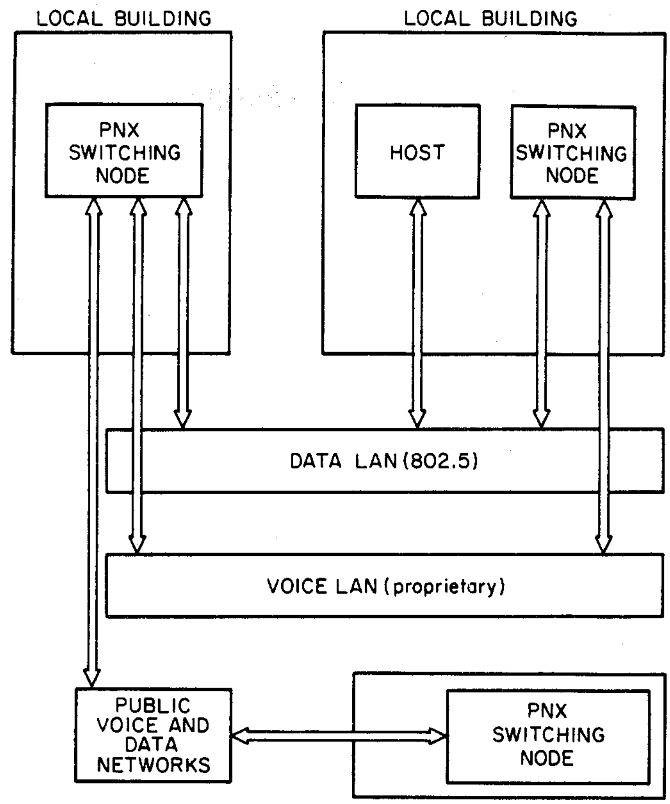


Figure 5-8. Distributed control for voice, data, and WAN access.

Contention (i.e., CSMA/CD) and deterministic (token bus, token ring) access methods are compared in tables that relate communication channel conditions.

An extensive description of IEEE project 802, ANSI, and military standards for local networks is given.

The IEEE project 802 standards are:

802.1 - overview, internetworking, and management

802.2 - logical link control

802.3 - CSMA/CD

802.4 - token-passing bus

802.5 - token-passing ring

802.6 - metropolitan networks.

The work of ANSC X3T9.5 is to develop standards for the Local Distributed Data Interface (LDDI) and the Fiber Distributed Data Interface (FDDI). Two topologies (i.e., bus and star) and transmission rates of 70 Mb/s and 100 Mb/s for High Speed Local Networks (HSLN) to be used in computer communications are involved.

Military standards 1553B and 1773 are intended for high-noise environments and feature extensive redundancy for reliability. MIL-STD-1773 is to use fiber optic cable and gradually replace MIL-STD-1553B that uses wire and cable.

Networking (both intra- and inter-), using bridges and gateway, is described by using a two-tiered model. One tier depicts the "real" subnetworks such as LAN's and WAN's, while a second tier depicts the layers of the OSI reference model and protocols within those layers. The tiers are aligned so that a correlation exists between the real and abstract components of network connections.

Descriptions of new fourth generation architecture that attempts to combine the best features of LAN's and PBX's are believed by some to be a method for optimizing integrated voice and data communications in a local network environment. Problems that are not to be overlooked can be reduced to a methodology for connecting disparate PBX's and LAN's.

Finally, the appendices in this report contain a description of the OSI reference model, a summary of protocols applicable within the framework of the reference model, and a limited survey of available bridges and gateways.

While this report has described components, standards, and examples of local networks, other criteria need to be considered in the selection process of one of these networks. These include:

- types of services (i.e., voice, data, video)
- number of devices on a network
- types of devices on the network
- distance between devices and network elements such as repeaters
- traffic characteristics
- acceptable transmission delay; i.e., real-time vs. store-and-forward
- required user response time before retransmission
- future growth as it effects the network loading.

A knowledge of the elements in this report along with these design considerations can lead to the selection of a local network that can serve the current and future needs of the user.

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APPENDIX A: OSI REFERENCE MODEL

This appendix contains a description of the Open Systems Interconnection (OSI) reference model as specified by the International Organization for Standardization (ISO). It provides an in-depth description for individuals desiring a detailed familiarity with the model. This tutorial is reproduced by arrangement with H.C. Folts, Omnicom, Inc., Vienna, VA.

A TUTORIAL ON THE OPEN SYSTEMS INTERCONNECTION (OSI) REFERENCE MODEL

Since this Open Systems Data Transfer tutorial was first published in June 1982, the work on the Open Systems Interconnection (OSI) architecture and protocols has advanced significantly, and now a number of related standards in the new family have been established.

In May 1983, the International Organization for Standardization (ISO) approved International Standard 7498 and the International Telegraph and Telephone Consultative Committee (CCITT) approved Recommendation X.200. Both these standards specify the basic OSI architecture in the form of a Reference Model. While both organizations fully intended to have consistent OSI Reference Model specifications, there were a number of editorial and technical differences in the approved versions. In the spirit of cooperation, however, the two groups reached agreement on the adjustments needed to make the two standards fully consistent. The final versions of ISO 7498 and CCITT X.200 will be published during 1984 and will contain identical text except for some introductory material that relates to the specific standards organization.

Protocols and service definitions have also been completed by ISO and CCITT for some OSI layers - Network, Transport, and Session. Others are in active development and will receive approval over the next couple of years.

This tutorial has been written to convey a basic understanding of the OSI architecture and the dynamics of operation necessary to support open and meaningful communications among systems of diverse design and manufacture. Other tutorials in the Open Systems Data Transfer series examine other elements of the emerging family of OSI standards for worldwide distributed information systems.

Hal Folts, August 10, 1984

A TUTORIAL ON THE OPEN SYSTEMS INTERCONNECTION REFERENCE MODEL

Harold C. Folts
Omnicom, Inc.

BACKGROUND

Although standards development activities for data communications applications started during the early 1960's, the real momentum did not build until the 1970's. By 1976, a number of standards were approved for public data networks, including CCITT Recommendation X.25 for packet-switched operation. Also near completion were the bit-oriented data-link control procedures (ADCCP in the USA and HDLC internationally). It was then realized that there was no master plan or structure for determining what standards were needed and whether all aspects of future distributed information systems were properly covered. Data communications standards work has been responding to immediate requirements, with little consideration given to the relationships among the various standards, proprietary protocols, and systems architecture.

The realization of this dilemma came about in 1977 when the International Organization for Standardization (ISO) Technical Committee 97 established a new Subcommittee (SC 16) to deal directly with this problem. SC 16, entitled Open Systems Interconnection, was chartered to develop an architecture to provide a framework for the definition, development, and validation of standards in the new generation of distributed information systems. The work was first directed toward a basic structure to define the functionality needed for communications among application processes remotely separated in different heterogeneous user end-systems.

The International Telegraph and Telephone Consultative Committee (CCITT) also recognized the importance of establishing a sound architecture and appointed a Special Rapporteur to study the problem and to work in close liaison with ISO. While the ISO work is more general, CCITT is directing its efforts to the application of the OSI to telecommunications services.

The Reference Model that has resulted from this intense effort has now evolved through 4 drafts and is in the final stages of approval in ISO. Currently identified as Draft International Standard (DIS) 7498 (February 1982), it is expected to be approved by the end of 1982 as an International

Standard. While the ISO Reference Model has been going through the approval process since mid-1981, the CCITT work has continued to advance editorially and has maintained full consistency with the principles established by ISO. A copy of the March 1982 CCITT Draft, Reference Model of Open System Interconnection for CCITT Applications, is included in Omnicom's OSI Reference.

The basic architecture specified by the OSI Reference Model is only the first in a family of standards that will result from this work. From the established principles of OSI, layer service definitions are now being developed that will then enable further development of the necessary protocols for communications among distributed application processes within the Open Systems Interconnection structure. The work will be ongoing and evolutionary. Now is the time to start to apply the new standardized OSI principles to all implementations that will be part of the worldwide distributed information era.

INTRODUCTION

The term 'open' is used to convey the ability of an end-system of one manufacturer (or design) to interconnect with any other end-system according to the OSI Reference Model and the associated standard peer protocols. This will enable application processes to communicate with each other through the resulting Open Systems Interconnection Environment (OSIE). Figure 1 illustrates an abstract of an Open Systems Interconnection - the OSIE is enclosed by the heavy line.

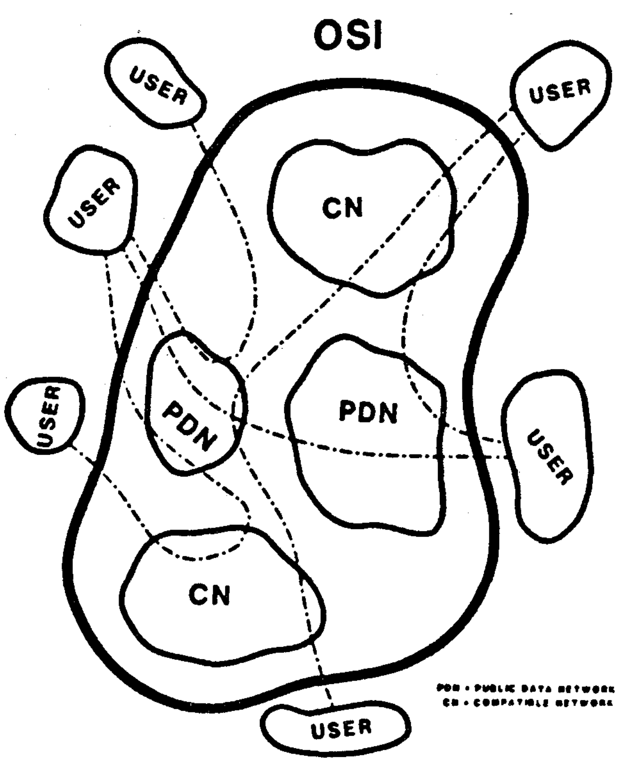

FIGURE 1

The 'user' is actually an Application Process (AP), which can be any sort of task from a simple program to a very complex operation. Examples of AP's include: a person operating a manual keyboard entry terminal, a credit checking program, an industrial production-line control program or sensor, plus an endless range of distributed computer processing applications. AP's may be one or a group of activities executing a set of procedures according to instructions established within the system to perform designated functions. In performing the overall task, AP's must be able to communicate, in order to share processing resources, access data bases, and deliver an output to an appropriate destination.

The user is outside of the OSIE, and when operating within its own end-system is considered to be closed. When a communication with another remotely located AP is needed, the OSIE is accessed, so that the user end-system becomes open. A number of intermediate systems may be transited from user to user through the OSIE. Shown in Figure 1 as Public Data Networks (PDN) or private Compatible Networks (CN), the telecommunications facilities are also an essential part of the overall OSI structure.

THE LAYERED ARCHITECTURE

A continuum of functions is involved in a communication, and they must be arranged in a logical order so that they can be understood. The technique of layering has been employed for this purpose in the OSI Reference Model. The first decision that had to be made was "how to slice the cake." There is almost an unlimited number of ways, and the final decision will always be somewhat arbitrary. Too many layers would make the structure too complex, while too few would lead to very complex protocols. It is also important to group functions that are most logically related to each other in supporting the communication. In the end, however, the decision made must be acceptable to the widest range of interests, both politically as well as technically. The division of seven layers of functionality has now been agreed upon worldwide to serve as a basis for the OSI architecture.

The layers of the OSI Reference Model are shown in Figure 2, and are briefly described as follows:

APPLICATION LAYER -
Directly serves AP by providing access to the Open Systems Interconnection Environment and provides the distributed information services to support the AP and manage the communication

PRESENTATION LAYER -
Provides the services that allow the AP to interpret the meaning of the information being transferred - syntax selection and conversion

SESSION LAYER -
Supports the dialog between cooperating AP's, binding and unbinding them into a communicating relationship

TRANSPORT LAYER -
Provides end-to-end control and information interchange with the reliability and quality of service that is needed for the AP

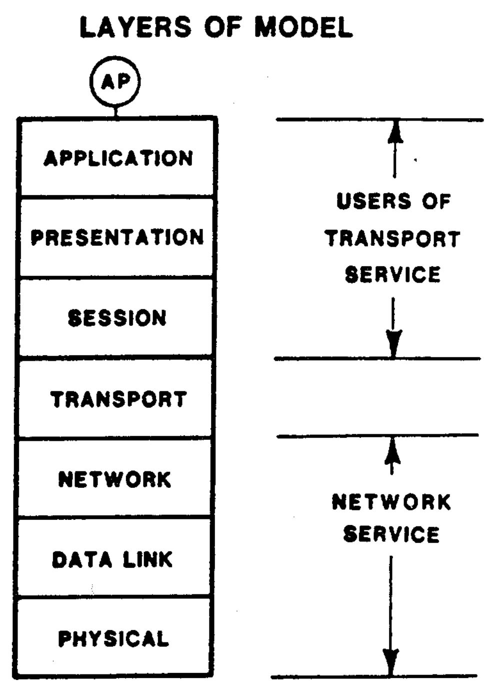

FIGURE 2

NETWORK LAYER -
Provides the switching and routing functions needed to establish, maintain, and terminate switched connections and transfer data between the communicating end-systems (NOTE - The term "network" as used here is a specific OSI technical term and should not be taken as denoting a

communications network in the conventional sense.)

DATA LINK LAYER -
Provides for the transfer of information over the physical link with the necessary synchronization, error control, and flow control functions

PHYSICAL LAYER -
Provides the functional and procedural characteristics to activate, maintain, and deactivate the physical links that transparently pass the bit stream of the communication.

The upper three layers provide the functions in direct support of the application process, while the lower three layers are concerned with the transmission of the information between the end-systems of the communication. The Transport Layer is the essential link between these two groups of functions; it provides end-to-end integrity of the communication, ensuring that the appropriate quality of service from the lower three layers meets the requirements of the upper three layers.

The specification of the characteristics of each layer individually provides the modularity that enables the functions and protocols to be defined independently - each performing its own task in supporting the communication. It then become possible to change a protocol at one layer without affecting the other layers and their protocols. Therefore, as technology evolves and new requirements emerge, OSI can advance into the future. This also enables application of the OSI structure now, and where suitable protocols are not available, temporary ones can be used. As the OSI protocols develop, then they can replace the ones in place without disturbing the whole system.

Each layer spans the whole interconnection within the Open Systems Interconnection Environment (OSIE) that supports the communication between cooperating AP's. As shown in Figure 3, within the OSIE, there are peer

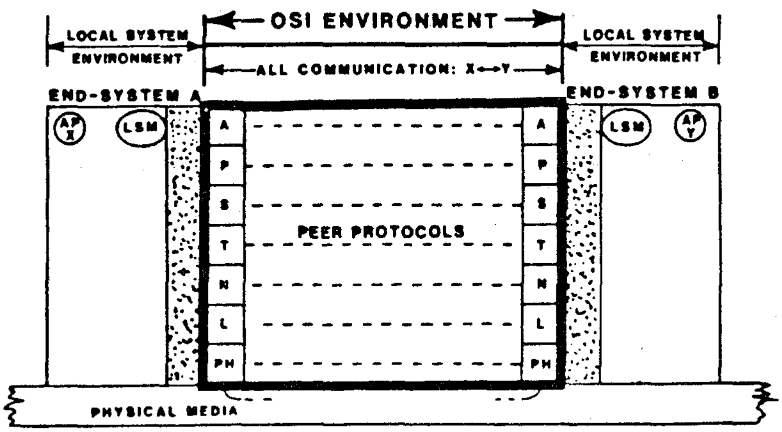

FIGURE 3

protocols that are needed to perform the control functions that support the communication. Each communicating application process is shown in the end-system within the local system environment. When a communication is desired, the AP, through the action of the Local System Manager (LSM), accesses the OSIE through the Application Layer. The OSIE is the area that is enclosed within the heavily outlined box. The physical media and the local system environment are external.

LAYER PRINCIPLES

As shown in Figure 4, each layer can be viewed individually as an (N) layer having an (N+1) layer as an upper boundary and an (N-1) layer as a lower boundary. The (N) layer receives services from the (N-1) layer and provides services to the (N+1) layer. In the case of the Physical Layer, however, the lower boundary is with the physical media rather than a (N-1) layer. The upper boundary of the Application Layer is with the application process.

CONCEPT OF A LAYER

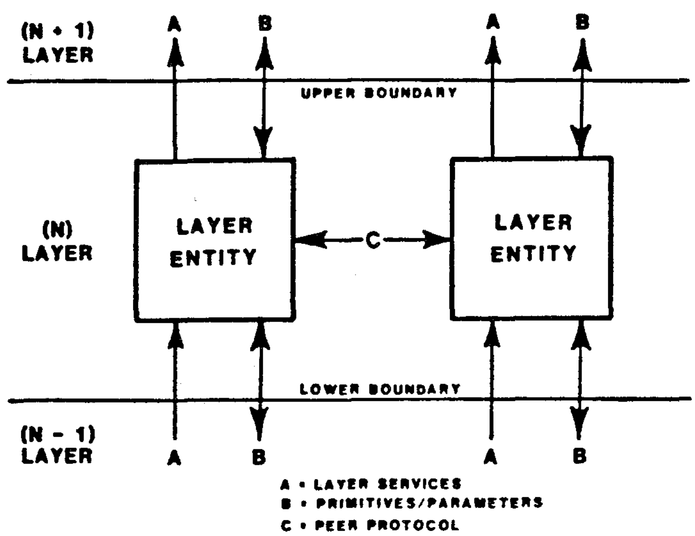

FIGURE 4

Each layer contains a logical grouping of functions that provide the specific services for facilitating a communication. A function, or a group of functions, within a layer makes a functional unit that is called an entity. An entity accepts one or more inputs (arguments) and produces outputs (values) determined by the nature of the functions. There may be two or more instances of active entities within each layer performing the functions that support the communication.

There are also interactions between entities of adjacent layers, in the form of requests, indications, responses, and confirmations. These are called primitives. Each primitive may also have associated parameters that convey detailed control information needed to support the communication.

There is an active entity, for each layer, in each system involved in the interconnection. Entities in the same layer communicate with each other using peer protocols that convey the necessary control information to support the communications between the cooperating AP's. While standard definitions are being developed for the services to be provided by each layer and for the associated interaction primitives, the OSI peer protocols that result will be the standards that will enable full OSI compatibility among systems.

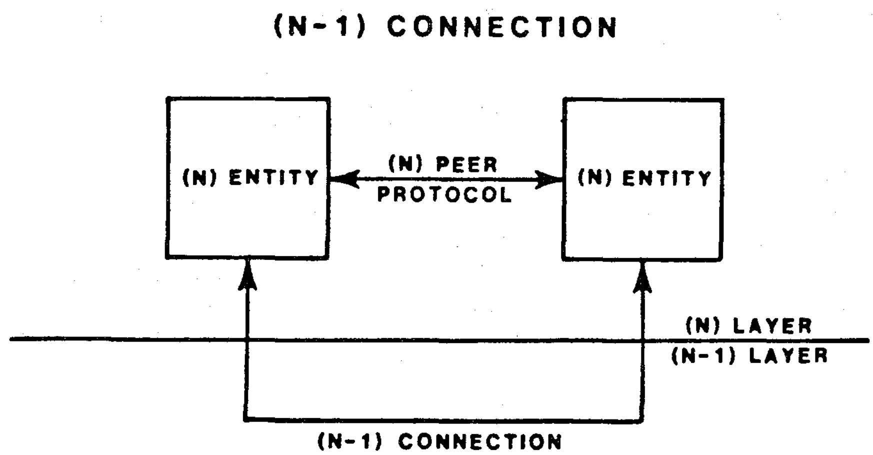

FIGURE 5

Information is exchanged between the layer entities through the use of the services of the (N-1) layer, which provides the logical connection path - the (N-1) connection shown in Figure 5 - between (N) layer entities. In turn, each layer utilizes the services of the lower layers, which are cumulatively reflected as the (N-1) services.

Entities of adjacent layers interconnect via layer service access points, as shown in Figure 6. The (N+1) layer knows the associated service access point by a service access point name, while the (N) layer knows the same point by a (N) service access point address. Mapping of addresses layer by layer for a connection may be accomplished either by hierarchical address mapping (inherent in the address structure) or through address mapping tables.

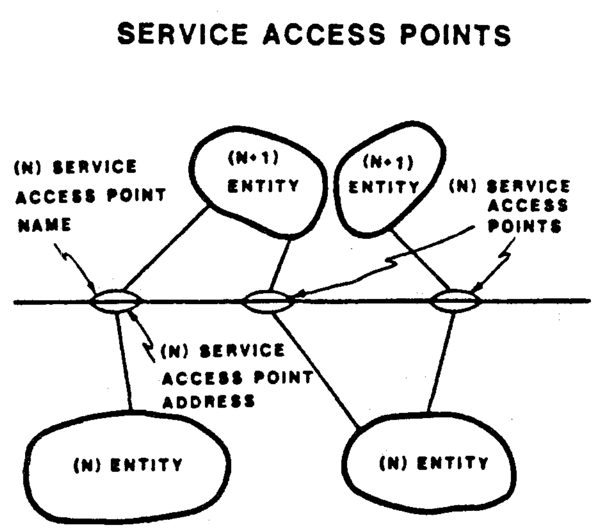

FIGURE 6

Interactions between adjacent layers are also key elements in supporting a communication. The primitives either initiate an action or advise the result of an action. Referring to Figure 7, the primitives are:

REQUEST - is initiated by the (N+1) layer to the (N) layer to activate a particular service

INDICATION - is provided by the (N) layer to advise of the activation of a particular service

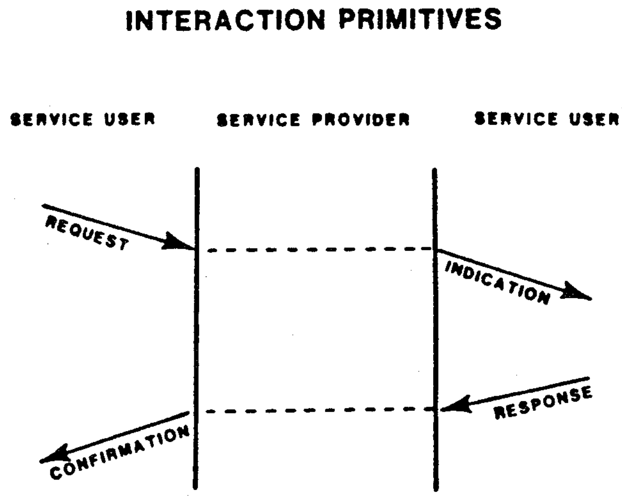

FIGURE 7

RESPONSE - is provided by the (N+1) layer in reply to an indication primitive

CONFIRM - is returned to the requesting (N+1) layer by the (N) layer upon completion of a requested service

Each primitive can have a number of associated parameters that convey additional specific information for the respective service. For example, a connection request primitive can contain the destination address, quality of service requirement, and data received from the next upper layer.

Information transfer takes place between peer entities within a layer as well as between entities of adjacent layers within the same system. The transfer is accomplished in the form of various types of data units, which are made up of control information and data. The basic construction of the information flow is shown in Figure 8.

The (N) Protocol Control Information (PCI) is exchanged between peer entities to coordinate their joint operation.

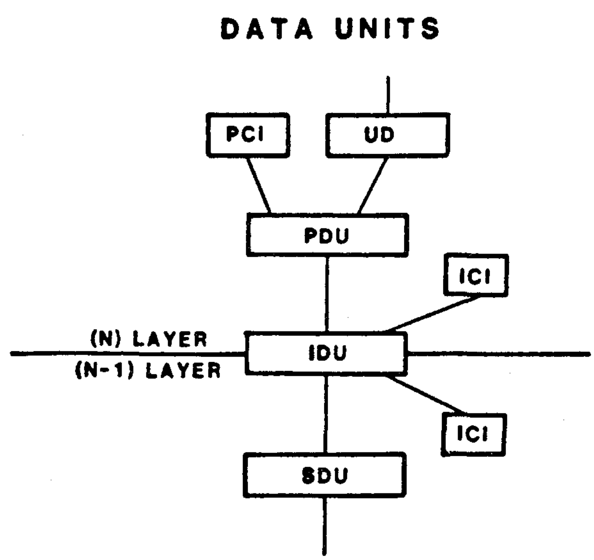

FIGURE 8

The (N) User Data (UD) may also be transferred between peer entities as required. In the (N-1) layer the UD becomes the (N) Service Data Unit (SDU).

The (N) Protocol Data Unit (PDU) is a combination of the (N) PCI and the (N) UD or (N) SDU. The (N) PDU is the total information that is transferred between peer entities as a unit.

The (N) Interface Control Information (ICI) provides the interaction between the adjacent layer entities. These are referred to as "Primitives" in the layer service definitions that are under development.

The (N) Interface Data (ID) is transferred between adjacent layer entities for the transmission to the peer entity via the (N-1) connection.

The (N) Interface Data Unit (IDU) is the total unit of information transferred across the service access point.

The (N-1) Service Data Unit (SDU) is the part of the IDU, whose identity is preserved between the ends of the connection.

This structure is followed layer by layer as the communication is processed through the interconnection. The terms for the different units used above are those as defined by the ISO DIS 7498. The CCITT Reference Model defines an (N) Boundary Data Unit (BDU) instead of IDU and does not define ICI or ID. (NOTE - The term "interface" is used in OSI to mean the boundary between adjacent layers and should not be taken as a connection between equipment.)

As the control information and data are processed by the entity within a layer the units may be segmented into smaller units or blocked into larger units as illustrated in Figure 9. This allows optimization of the information transfer through efficient utilization of the resources en route. For example, a very large (N) PDU may be segmented across many (N-1) PDU's in processing the communication.

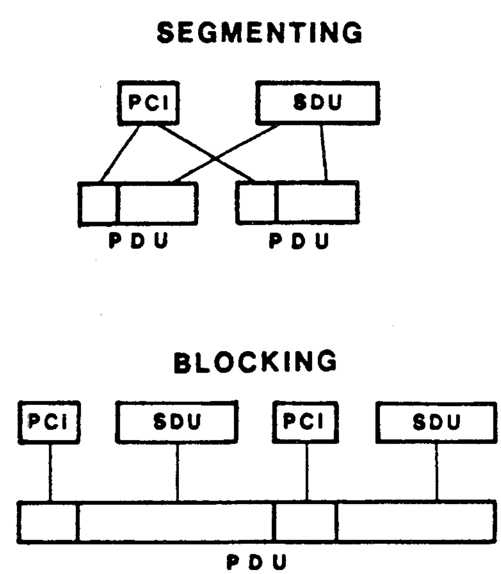

FIGURE 9

Many elements of operation are common to most layers and can be treated in general. These are:

Protocol selection - More than one protocol may be defined for a layer to meet different requirements and applications. Therefore, a mechanism is required to properly identify the protocol for the specific communicating application process.

Connections - An (N) connection is an association for communication between two or more (N+1) entities. Connections are established and released as needed during a communication. They may be point-to-point or multipoint.

Multiplexing - An entity may support the connection of more than one (N+1) entity over a single (N) connection.

Splitting - A layer may use more than one (N) connection to support a single (N+1) layer entity.

Data transfer - Normal data transfer takes place over the primary path, while expedited data can bypass the normal data to support recovery or other infrequent operations.

Flow control - Because of limited capacity to hold data while the control information is being processed, it is necessary to manage the flow of the information both between entities of adjacent layers and between peer entities within a layer.

Sequencing - In some networking configurations, it may be possible for the information to arrive at the destination in a different order from that sent by the source. Before it can be processed further, it may be necessary to put the information back into its original order.

Acknowledgement - Receipt of confirmation that data has been received at the appropriate destination and is acceptable may be necessary at several layers, depending on the quality of service requirements of the corresponding application processes.

Reset - If synchronization is lost or some unrecoverable error occurs, it may be necessary to reinitialize the connection between peer entities.

Routing - This function enables the communications to be relayed by a chain of entities within the layer.

Not all functions are necessarily invoked in each layer for every communication. Only those that are needed to support the specific application are activated. It is also possible that there may not be a need for any functions within a particular layer. What will be considered the minimum functionality of any individual layer is still being debated.

For any system to operate properly, there must be orderly management to ensure all components work in harmony. The management aspects of OSI include the control of initiation, termination, monitoring, and handling of abnormal conditions. There are three management areas that need to be considered:

Application management - involves: initialization of parameters; initiation, maintenance, and termination of the communication; detection and prevention of OSI resource interference and deadlock; integrity and commitment control; security control; and checkpointing and recovery control.

Systems management - involves control of the OSI resources and their status across all the layers.

Layer management - is concerned with the activation process, error control, and coordination of activities within a layer.

Development work in these management areas is in the early stage and is now getting more attention as the work on the basic reference model has reached a good level of maturity and wide agreement.

COOPERATING OPEN SYSTEMS

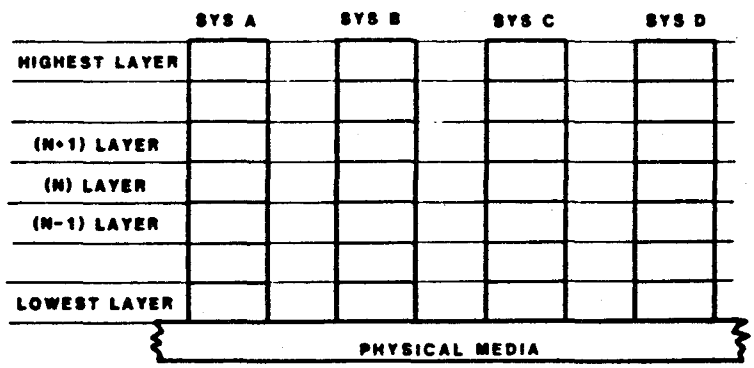

FIGURE 10

As earlier mentioned, each layer logically transverses all the interconnected systems that are in a cooperating relationship in the OSIE. At each interconnected system there are layer entities that interact with peer entities in the other connected systems via the peer protocols to facilitate the communication. As shown in Figure 10, the physical media provides the connecting path between the respective systems. While all seven layers in the

RELAY FUNCTION

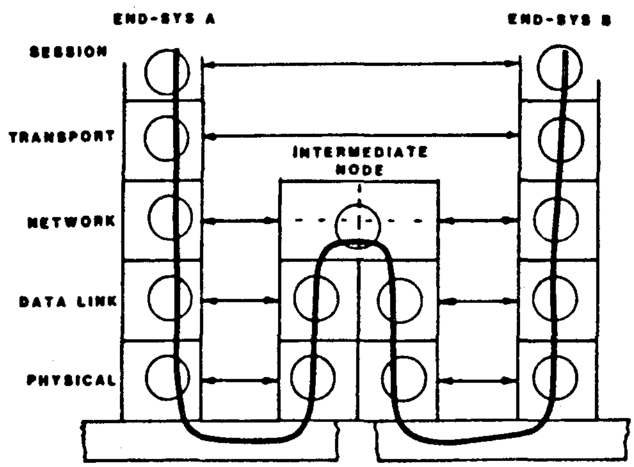

FIGURE 11

connected end-systems are functionally active, intermediate (or relay) systems may only have active entities in the lower three layers, as in the case of a packet-switched network, shown in Figure 11. The circles show the activated entity at each layer in each interconnected system. In this case, there are two physical connections and two data links that are in tandem to make up the full network connection. The active network layer entity in the intermediate system performs the relay function between the two links and provides continuity of communication path. A typical relay system may involve only the physical layer. An intermediate system involving all seven layers is an example used for store and forward message transfer.

There are unlimited configurations that can be created when mapping the OSI structure into an actual system or in designing a new system. By using diagrams like Figure 11, it becomes much easier to identify the actual structure of the total system at hand. This technique is now being used in CCITT for the development of the standards for the new Integrated Services Digital Networks (ISDN).

AN OSI SCENARIO

To illustrate the OSI principles in operation, a simple scenario is presented, using the configuration in Figure 12. The two communicating end-systems are shown, while the relay systems are only implied in this example. In each peer relationship the (N) protocol control information is shown as a header (H), which, combined with the data unit, creates the (N) protocol data unit that is logically transferred between the peer entities. For the Data Link Layer the actual X.25 format is shown rather than a general header. The peer relationships are horizontal, while the actual information flow follows the dotted line.

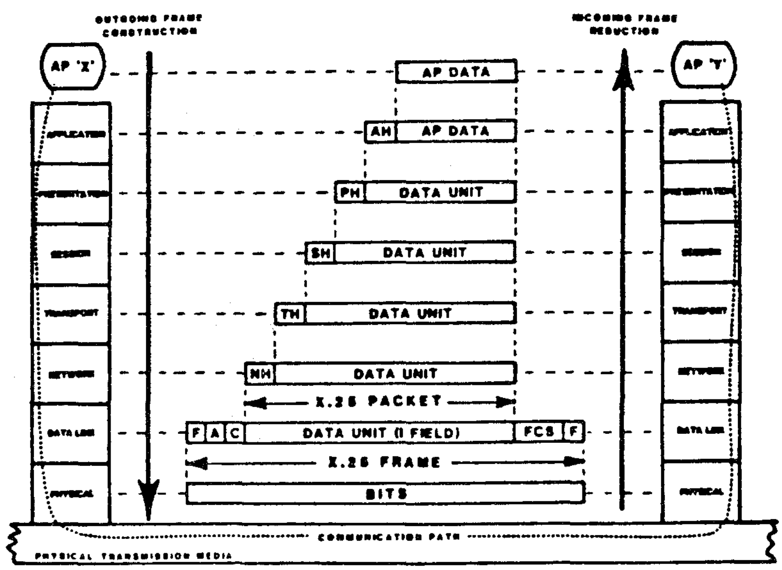

FIGURE 12

Application Process X finds a need to communicate with Application Process Y in a remotely located system. AP X then accesses the OSIE by requesting the Application Layer to establish the required communication. The Application Layer determines the availability of the OSI resources to support the communication. If available, the communications establishment begins with a series of request primitives that repeat from layer to layer down through the next six layers as each layer entity is activated in the originating end-system. At the bottom, the Physical Layer entity activates the physical link and the respective peer entity. Then the Data Link Layer activates the peer protocol, and the Network Layer establishes the network connection to the destination end-system. In turn the end-system to end-system peer relationships for the Transport, Session, Presentation, and Application Layers are established. As this takes place each layer is advised of the incoming communication from the layer below by indication primitives, and acceptance is returned to the next lower layer through a response primitive. In completion of the activation of each layer's peer relationship and the communication path, a confirmation primitive is returned to each layer upward at the originating end-system. When this process is completed, the communication between the AP's proceeds.

AP X passes the data to the Application Layer, where the application protocol header (AH) is added to convey the peer protocol information to the application entity in the destination end-system. This is the application protocol data unit that becomes the service data unit at the Presentation Layer (assuming a one-to-one relationship). The Presentation Layer then adds its protocol control information header (PH) that will be carried to its peer at the other end-system. The presention entity may also perform a syntactic transformation on the application data. The appending of protocol control information onto the data units follows layer by layer as the outgoing frame is constructed through the Data Link Layer. At the Physical Layer the information is seen only as a flow of bits to the transmission media. En route there may be a number of relay systems where switching and routing functions are performed at the network layer or between transmission media at the Physical Layer. A relay function within the Data Link Layer is also possible if, for example, certain types of Local Area Networks are traversed.

At the destination end-system the bit flow enters the Physical Layer from the transmission media and is passed on to the Data Link Layer. The flags (F) of the X.25 frame synchronize the information while the address (A), control (C), and frame check sequence (FCS) information is used for the various data-link control functions. These are then removed from the frame and the data unit of the I field is passed to the Network Layer. (In the X.25 example, this is a packet.) The network entity then looks at the header (NH), performs its required function, and passes the remaining data unit to the Transport Layer. Each layer in turn looks at its header, performs the required functions, and passes the remaining data unit to the next upper layer until the final application process data is delivered to AP Y. This construction and reduction of the information flow associated with the communication takes place in both directions until the communication is completed. Then the resources are released and become available for subsequent communications.

Although this scenario is simplified and represents only one of many possible situations, the basic OSI process is shown. Some applications may activate all the peer relationships in parallel during the establishment procedures, while others may activate each layer sequentially one at a time. While this example may give the impression of an excessive amount of overhead and control information to transfer the data between the application processes, bear in mind that only the functions that are needed are actually invoked. Furthermore, larger data units from upper layers may be segmented or blocked according to the resources and nature of the communication. In overall system operation the total protocol control information should be small compared to the AP data being transferred.

LAYER SERVICE DEFINITIONS

The basic OSI Reference Model provides only the general description of each layer. The next step in the OSI development process is the preparation of a service definition for each layer that will define the functions, services and associated primitives in greater depth. When the service definitions are completed, the layer protocols can then be identified, if existing, or developed where they do not exist. The latter is generally the case except for a few existing protocols that will be fully adapted into the OSI structure, such as X.25, X.21, and HDLC. Further details of the layer service definitions and protocols will be subjects of future OSI Data Transfer tutorials. Below are brief presentations of the functions and services that are defined in the basic OSI Reference Model.

Application Layer

The Application Layer serves as the window for the application process to access the Open Systems Interconnection Environment. This is the only layer that provides services directly to the application process. These services, however, reflect the accumulation of the results of all the services provided by the underlying layers. The definition of the Application Layer is just now starting to take shape and settle.

APPLICATION LAYER ELEMENTS

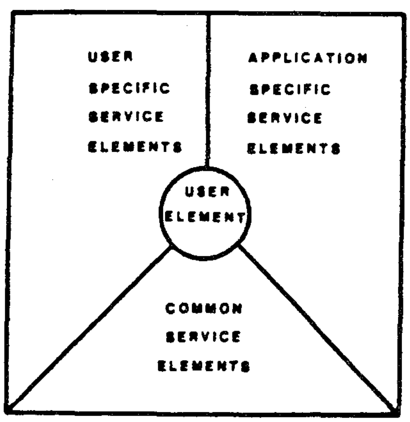

FIGURE 13

The advanced definition in the CCITT OSI Reference Model identifies three categories of service elements (see Figure 13) - common, application-specific, and user-specific. The common elements furnish the capabilities for an OSI communication independent of the nature of the specific application. The application-specific elements are required by certain categories of applications to support the functions of the information transfer process, such as file transfer, virtual terminal, and job transfer and manipulation. The user-specific elements apply to the functions that are unique to the specific application area, such as airline reservations and banking.

For particular communications, functions from all three service elements may be invoked. While the common elements provide and control the access of the AP to the OSIE, the file transfer elements may be used from the application-specific elements together with electronic funds transfer elements that are user-specific. As a result, eventually there will be a large number of protocols developed for the application layer to meet the wide variety of specific user needs. Work in the area of file transfer and virtual terminal is now making good progress in developing general-purpose Application Layer protocols.

Presentation Layer

The Presentation Layer ensures that the information is delivered to the communicating application process in a form that can be used and understood. While the meaning - semantics - of the information is fully preserved, the format and language differences - syntax - are resolved.

If the communicating application processes both use the same syntax, the functionality of the Presentation Layer does not have to be invoked. With open systems, however, this is not always the normal situation. Therefore, the Presentation Layer provides for syntax selection to specify the format of the data and choose from alternative encodings.

Within a communication, it is possible to have the information appear in three different syntaxes - local to source, local to destination, and between Presentation Layer entities. The illustration in Figure 14 shows an example where three syntaxes are used, French, English, and German, and where the translation is accomplished in both end-systems.

Work is proceeding well in this area. ECMA has issued a general-purpose data-presentation protocol. In CCITT there is an active issue to resolve the presentation syntax and protocol for Videotex applications. There are presently 15 possible code sets that can be employed out of the North American and European proposals. The issue at hand is to resolve a common procedure for selecting the appropriate code set for a particular Videotex communication.

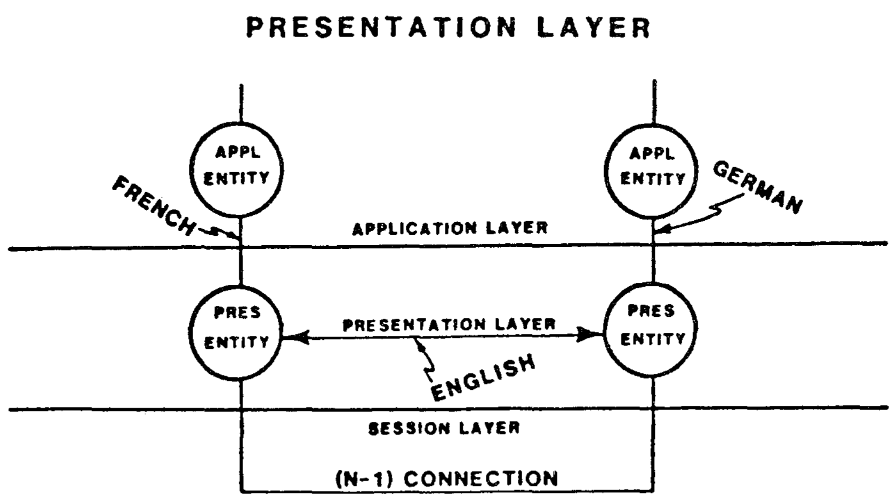

FIGURE 14

Session Layer

The Session Layer provides the means for the cooperating presentation entities to organize and synchronize their dialog and manage their data exchange. As with other layers, the Session Layer provides a connection to bind the upper layer entities and application processes into a logical communicating relationship.

As shown in Figure 15, consecutive session connections may be established and terminated over one continuous transport connection. On the other hand, one continuous session connection can be maintained over a number of transport connections that are established and terminated sequentially. Before connections are released, however, the session entity ensures that all the information en route has been received at the destination, so data are not inadvertently lost.

Both normal and expedited data exchange can take place. The expedited data may bypass normal data flow to facilitate recovery procedures or some other occasional special procedure needed for operation.

A quarantine service is provided by the Session Layer so data can be held and released for delivery to the destination only upon explicit command from the source. It may also be decided by the source, after preparing the quarantined data, that it is not to be delivered and is to be purged. (This feature was challenged and was omittedinthefinalversions.)

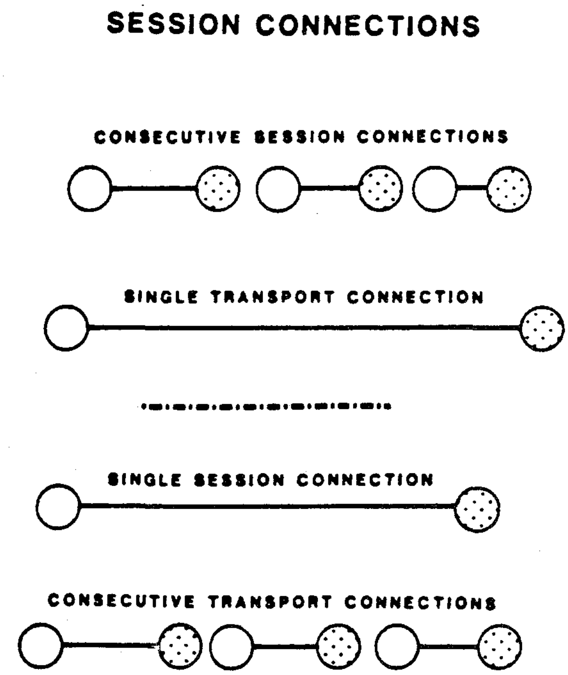

FIGURE 15

The Session Layer also provides for interaction management of the communication. In applications where dialog control is needed, management of whose turn is it to send is handled - two-way alternate or two-way simultaneous. When errors occur in the data flow, a resynchronization procedure can be invoked to recover the missing data.

Currently there are two standards published for session protocols. The first is CCITT Recommendation S.62, which was developed initially for the new Teletex services - communication among office word processing systems. CCITT is using this as the basis of further work for facsimile and videotex services as well as a general purpose superset. ECMA published their first session protocol standard, ECMA 75, in January 1982. This will also serve for initial implementations and provide a basis for further work. In June 1982, ISO/TC 97/SC 16 passed a resolution that would enable the draft Session Protocol to be balloted as a Draft Proposal in early 1983.

Transport Layer

The Transport Layer is the lowest layer, whose peer entities are always in the communicating end-systems (see Figure 16). The functions of this layer do not become involved in an intervening telecommunications network or relay nodes. The basic purpose of the Transport Layer is to provide a consistent Transport Service in association with the lower three layers. It will optimize the use of the network services and correct for deficiencies in quality of service to meet the requirements of the upper layers and communicating application processes.

TRANSPORT CONNECTION

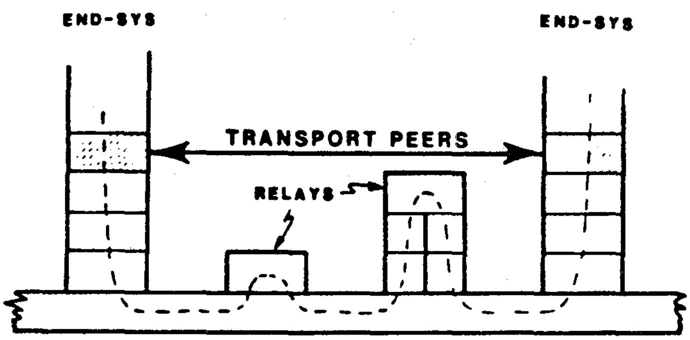

__FIGURE 16__

There are presently five classes of transport protocols being developed to meet a wide range of requirements. Since the Transport Layer is the bridge between the application-related functions and the transmission-related functions, it is key to the operation of the OSI. If the underlying network services are poor and the application requires a high quality of service, the transport protocol must take care of the differences. On the other hand, if the network services meet the requirements of the application, little transport functionality is needed.

Among the functions that may be performed by the Transport Layer are: establishment of transport connections, error recovery, multiplexing, flow control, and error detection. As with other layers, only the functions that are needed for the particular situation are invoked for a specific communication. These can be negotiated during the establishment of the communication.

In 1980 CCITT published the first transport protocol in Recommendation S.70 for the new teletex services. It was a very minimal protocol to serve the specific application. In January 1981, ECMA published their transport protocol, ECMA 72. This has served as the basis for the further work in both ISO and CCITT. The National Bureau of Standards has also contributed to the development of the highly functional class 4 of the family of transport protocols. In June 1982, ISO/TC 97/SC 16 approved the draft Transport Protocol to beballoted as a Draft Proposal. If all goes well, it could be approved by mid-1983.

Network Layer

The Network Layer is responsible for the routing and relay functions through switched telecommunications media. It provides the network connection between transport entities and can multiplex two or more network connections over a single data link access to a relay node, as shown in Figure 17.

NETWORK ROUTING & SWITCHING

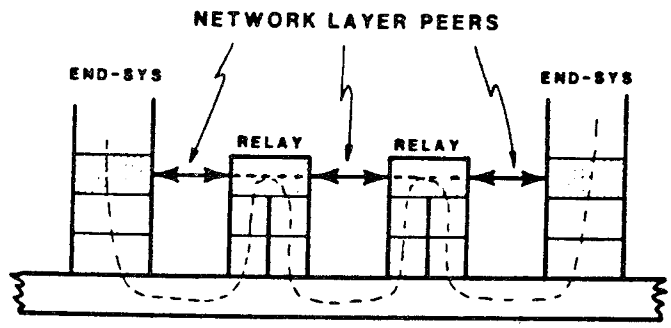

FIGURE 17

Among the other services that the Network Layer provides are both normal and expedited data transfer, error notification, peer flow control, sequenced data, and reset. Another service optionally provided is receipt confirmation. When requested by the transport entity, the network entity will monitor the delivery and receipt of information to the destination transport entity. When the destination transport entity returns an acknowledgement to the network entity, notification is conveyed to the source transport entity via the network peer protocol and indication acknowledge primitive.

As a result of the ISO/TC 97/SC 16 meeting in Tokyo inJune 1982, the receipt confirmation service will be recognized by the OSI Reference Model for optional use by only one class of Transport Layer protocol when the features of CCITT Recommendation X.25 are applied.

Data Link Layer

The Data Link Layer is responsible for the reliable transfer of information over the physical transmission media. A connection between end-systems may comprise a number of data links in tandem (see Figure 18) - each functioning independently, but contributing to the total communication process.

The Data Link Layer provides the synchronization of the information to delimit the flow of bits from the Physical Layer and give it identity. It also provides for peer flow control of the information so that receiving buffers do not become overloaded. Finally, the Data Link Layer provides for detection of transmission errors and mechanisms to recover from lost, errored, or duplicated information.

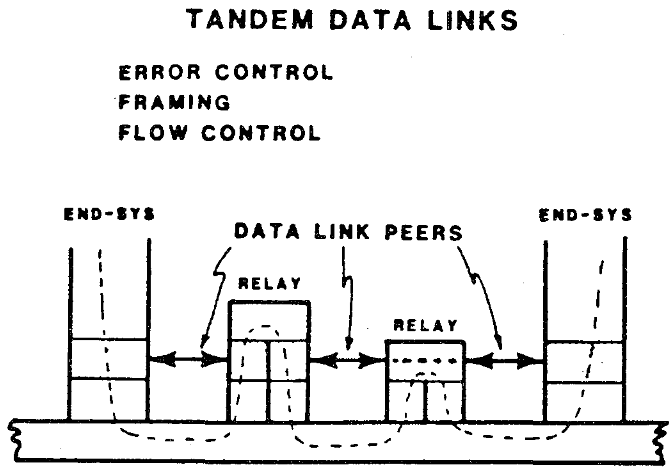

FIGURE 18

If a fully functional protocol is invoked for this layer, upper layers can assume that the information received is free of transmission errors, although there is always a finite probability that there will be undetected errors.

Existing protocols that fall within the Data Link Layer are the well-established character-oriented procedures, ANSI X3.28 or ISO 1745, known as basic mode or Bisync. The new bit-oriented procedures of ANSI X3.66, Advanced Data Communication Control Procedures (ADCCP), ISO's High Level Data Link Control (HDLC), LAP B of CCITT Recommendation X.25, and the single link procedure of CCITT Recommendation X.75 are also within the definition of the OSI Data Link Layer.

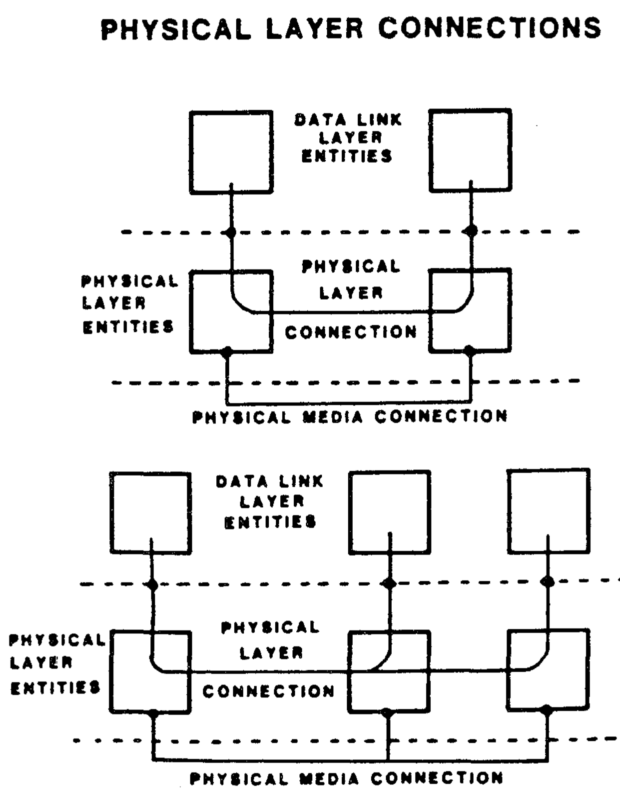

FIGURE 19

Physical Layer

The Physical Layer provides the functional and procedural characteristics to activate, maintain, and deactivate the physical link through the transmission media. In ISO's DIS 7498 the Physical Layer definition also includes the electrical and mechanical characteristics. These have been eliminated from the advanced CCITT draft of the OSI Reference Model. Since layer entities deal only with logical relationships, CCITT proposes that the electrical and mechanical characteristics actually represent the physical interface with the transmission media. Thus the logical physical connection between peers, when activated, does not directly represent the physical media. The physical media is outside of the OSIE and only represents the path over which the bits flow.

The Physical Layer deals only with bits received from and passed up to the Data Link Layer. It may provide a multiplexing function for multiple data links over a single Physical Layer connection. Physical Layer connections may be either point-to-point or multipoint, as shown in Figure 19. The relay function also applies where the connection is made up of tandem transmission media.

Existing standards within the Physical Layer include the well-known EIA RS-232-C as well as EIA RS-449, CCITT V.24, and physical elements of CCITT Recommendation X.21.

CONCLUSION

During the first four years of the OSI development work, substantial progress has been made through active and intense effort. Now that the basic structure and principles are well agreed upon, the progress of the work is gaining a much more rapid pace. If one asks, "When will OSI be finished?" the answer is "never." The work will be ongoing and evolutionary as technology advances and new requirements emerge. Those that start applying the OSI principles now will also be able to evolve their systems with the OSI work. Where particular parts are not complete, proprietary designs will have to be employed, but if they are done within the OSI framework, they can be replaced with OSI standards in the future.

The approval process in ISO is slow; therefore, a delay of 18 to 24 months can be expected from completion of a Draft Proposal to final approval of the International Standard. The CCITT, however, has speedier mechanisms for timely approval when needed.

The ISO Reference Model DIS 7498 is expected to be approved by the end of 1982, while the more advanced version for CCITT Applications is expected to be processed under the accelerated procedures and approved by Spring of 1983.

The Transport protocol started the ISO approval process in June 1982, and CCITT may invoke the accelerated procedures, which could give overall approval by mid-1983. The work on Session Layer protocols is advancing, with ISO and CCITT drafts expected in 1983. It should be noted that ECMA 75 and CCITT Recommendation S.62 already exist.

The remaining upper layer work is also making progress, with mature drafts expected in 1984. Again ECMA is pioneering the way and will be issuing the first standards for the Presentation and Application Layers during 1982 and 1983.

In addition to the protocols, active work is underway to develop a formal specification language that will be used to define unambiguously the OSI peer protocols as well as the OSI Reference Model itself. This work is expected to be completed by 1984. Activity on the OSI management aspects and associated protocols is just getting underway, but the pace is expected to quicken, so the results should be only a couple of years away.

The OSI Reference Model presently deals only with a connection-oriented mode of operation. That is where a path for the communication to follow is established prior to the communication. A connectionless mode of operation also has some popularity and is being prepared as an addendum to the OSI Reference Model. Connectionless communications do not pre-establish a path, but route individual units of information as they are sent. The optional datagram service in CCITT Recommendation X.25 is an example of connectionless operation, while virtual circuit service is an example of a connection-oriented communication.

Some think the above statements may be very optimistic, but industry is quickly realizing the importance of the new generation of standards for distributed information systems. These are key to the realization of compatible operation worldwide. The days are now passing where any one manufacturer's design becomes the de facto standard in the market place. OSI is leading the way to sensible, usable standards that will serve the widest range of interests and applications in the very near future.

APPENDIX B: APPLICABLE PROTOCOLS

The CCITT and ISO Open Systems Interconnection (OSI) reference models (Recommendation X.200 and International Standard 7498, respectively) provide an architectural structure for developing communication standards. Table B-1 provides a summary of protocols that fit within the layer service definitions of the OSI environment.

As can be seen in the table, the development of communication protocols has been concentrated in physical, data link, and network layers. Protocol development is progressing at the transport layer, while a significant amount of work is required at the upper layers.

The MIL-STD-1777, Internet Protocol (IP), and MIL-STD-1778, Transmission Control Protocol (TCP), are recognized DoD protocols. However, the TCP is considered incompatible with the CCITT/ISO transport layer service definition. A study by the National Academy of Sciences has recommended that the Department of Defense (DoD) convert to CCITT X.224 and the equivalent ISO 8073 as transport layer protocols. Whether the DoD will make the change is not known (Omnicom, 1984).

Reference B-1

Omnicom (1984), Comment, Open Systems Communication, October. Available from Omnicom, Inc., Suite 206, 501 Church Street, NE, Vienna, VA 22180.

Table B-1. Applicable Protocols

OSI Layer						
Physical	Data Link	Network	Transport	Session	Presentation	Application
CCITT: X.21 X.21 bis	Asynchronous: Start-Stop	CCITT: X.21 X.25 X.75 (1)	CCITT: X.224 (2)	DoD: Telnet		DoD: File Transfer (FTP)
EIA: RS-232-C RS-449 RS-422 RS-423	ANSI: ADCCP	Autodial Request-Response	ISO: IS 8073 (2)			Simple Mail Transfer (SMTP)
ISO: V.24 V.28	ISO: HDLC	DoD: Gateway-Gateway (GGP) (1)				CCITT: X.400
	IEEE: CSMA/CD Token Bus Token Ring (LLC/MAC)	MIL-STD-1777 • Internet (IP)	MIL-STD-1778 • Transmission Control (TCP)			
	Burroughs: BDLC					
MIL-STD-188	IBM: BSC SDLC					
	Sperry: UDLC					

Notes: 1) Gateway protocol
2) Equivalent transport layer protocols

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Local networks, related standards activities of the Institute of Electrical and Electronics Engineers (IEEE) Project 802, the American National Standards Institute (ANSI), and other elements are presented. These elements include 1) technology choices such as topology, transmission media, and access protocols; 2) descriptions of standards for the 802 local area networks (LAN's); high speed local networks (HSLN's) and military specification local networks; and 3) intra- and internetworking using bridges and gateways with protocols conforming to the framework of the Open Systems Interconnection (OSI) reference model. The convergence of LAN/PBX technology is also described.

16. Key Words *(Alphabetical order, separated by semicolons)*

baseband, broadband, carrier sense multiple access with collision detection (CSMA/CD); high-speed local network (HSLN); IEEE project 802; internetworking; intranetworking; local networks; local area networks (LAN); Open Systems Interconnection (OSI); private branch exchange (PBX); token bus; token ring

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